UNCLASSIFIED

COPY NO. 67

TECHNICAL MEMORANDUM

FLIGHT TEST AND ENGINEERING GROUP
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND 20670-5304

TM 93-59 SY

IN-FLIGHT MEASUREMENT OF AIRCREW BREATHING IN NAVY AIRCRAFT

by

Mr. Dennis N. Gordge

Systems Engineering Test Directorate

20 September 1993

Approved for public release; distribution unlimited.

UNCLASSIFIED

DEPARTMENT OF THE NAVY
FLIGHT TEST AND ENGINEERING GROUP
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND 20670-5304

N62269/93/WX/0006
TM 93-59 SY
20 September 1993

This Technical Memorandum presents results of the in-flight measurements of aircrew breathing in Navy aircraft. This work was performed for NAVAIRWARCENACDIV Warminster under Order for Work and Service Direct Citation Document No. N62269/93/WX/0006.

This report supports the requirements of the Order for Work and Service.

APPROVED FOR RELEASE:

T. E. Fleischman

T. E. FLEISCHMAN
By direction of the Director,
Flight Test and Engineering Group
Naval Air Warfare Center Aircraft Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
20 SEPTEMBER 1993

3. REPORT TYPE AND DATES COVERED
TECHNICAL MEMORANDUM

4. TITLE AND SUBTITLE
IN-FLIGHT MEASUREMENT OF AIRCREW BREATHING IN NAVY AIRCRAFT

5. FUNDING NUMBERS

6. AUTHOR(S)

MR. DENNIS N. GORDGE

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

FLIGHT TEST AND ENGINEERING GROUP
NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
DEPARTMENT OF THE NAVY
PATUXENT RIVER, MARYLAND 20670-5304

8. PERFORMING ORGANIZATION REPORT NUMBER

TM 93-59 SY

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
WARMINSTER, PENNSYLVANIA 18974

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A man-mounted, aircraft independent, self-contained recording system was developed for measuring the breathing flow rates of aircrew during all phases of flight. Breathing data of 41 Navy and Marine Corps aircrew operating F-14, F/A-18, A-7, A-6, and S-3 aircraft were measured during 51 flights including fleet combat exercises. The data were collected to validate current test and evaluation techniques and to modify oxygen system design and installation specifications. The data may also be used for designing future oxygen systems. The data generally show good correlation with previous studies, but also provide unique results for carrier operations and aerial combat maneuvering (ACM) conditions not previously reported. The results indicate that the current military oxygen system flow rate specifications are inadequate for tactical aircraft performing ACM. The results also suggest that current F-14 and F/A-18 oxygen systems may be inadequate for low altitude ACM. The point of contact for this work is Mr. Dennis Gordge, telephone (301) 826-3116.

14. SUBJECT TERMS

OXYGEN SYSTEM	BREATHING REQUIREMENTS		ANTI-G STRAINING
MANEUVER	OBOGS	LOX	OXYGEN FLOW

15. NUMBER OF PAGES
74

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

SUMMARY

A man-mounted, aircraft independent, self-contained recording system was developed for measuring the breathing flow rates of aircrew during all phases of flight. Breathing data of 41 Navy and Marine Corps aircrew operating F-14, F/A-18, A-7, A-6, and S-3 aircraft were measured during 51 flights including fleet combat exercises. The data were collected to validate current test and evaluation techniques and to modify oxygen system design and installation specifications. The data may also be used for designing future oxygen systems. The data generally show good correlation with previous studies, but also provide unique results for carrier operations and aerial combat maneuvering (ACM) conditions not previously reported. The results indicate that the current military oxygen system flow rate specifications are inadequate for tactical aircraft performing ACM. The results also suggest that current F-14 and F/A-18 oxygen systems may be inadequate for low altitude ACM. The point of contact for this work is Mr. Dennis Gordge, telephone (301) 826-6116.

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

1. Oxygen system design requirements for tactical aircraft have required system and components to be smaller, lighter, and more reliable with better performance and less maintenance. High performance military aircraft need oxygen systems that provide adequate flow to meet the aviator's dynamic breathing demands throughout the entire flight envelope. Liquid oxygen (LOX) based systems have historically been designed around a nominal steady flow requirement. The introduction of molecular sieve based On-Board Oxygen Generating Systems (OBOGS) required more detailed analysis. OBOGS performance is a function of engine bleed-air pressure, aircrew breathing demand, and aircraft operating conditions such as altitude and temperature. The integration of OBOGS into tactical aircraft such as the AV-8B, T-45, F/A-18, and F-14D requires an in-depth knowledge of both aircraft characteristics and aircrew breathing requirements.

2. NAVAIRWARCENACDIV Patuxent River was tasked by reference 1 to broaden the knowledge base of tactical aircrew's dynamic breathing efforts in mission related operational scenarios. This data base was required to verify current test and evaluation techniques used in analyzing the dynamic performance of oxygen delivery systems such as aircraft mounted OBOGS, as well as emergency or back-up oxygen systems, and oxygen system components (oxygen masks, regulators, etc.). NAVAIRWARCENACDIV Patuxent River developed a man-mounted, aircraft independent, digital data instrument recorder for measuring the breathing flow rate of aircrew during ground and flight operations. Testing was conducted as a piggy-back effort, on a not-to-interfere basis, from June 1986 to March 1987. Additional testing was planned for September-October 1987 but was precluded by scheduling conflicts and technical difficulties. The accumulated data were assembled into a working data base and have since been used for updating oxygen systems dynamic flow specifications. This report provides formal documentation of the program and the results obtained therein. The completion of this effort was authorized by reference 2.

PURPOSE

3. The purpose of the test was to acquire aircrew in-flight breathing data to validate oxygen system test and evaluation techniques and to modify oxygen system design and installation specifications. A primary objective of the program was to obtain breathing data from a cross-section of Naval aircrew flying an assortment of Navy aircraft in typical operational scenarios.

DESCRIPTION OF EQUIPMENT

4. In-flight measurements were acquired using standard configuration F/A-18, F-14, A-6, A-7, and S-3 aircraft. Flights using AV-8B aircraft were aborted due to aircraft failures not related to this program. Aircrew included pilots (all aircraft types), NFO's (F-14 and S-3), and BN's (A-6). Experience levels ranged from student pilots to highly experienced instructor and test pilots.

SCOPE OF TESTS

5. Data were recorded during the operating conditions listed in table I. A more thorough description of each category is given in appendix A. The actual number of flights in each aircraft type is shown in table II.

Table I

OPERATING CONDITIONS

Conditions	Percent of Data Base (By Number of Breaths)
1. System Checkout, Base Line, Taxi, and Other Ground Operations	3.6
2. Routine In-Flight Operations	38.6
3. Conventional Take-Off	6.0
4. Conventional Landing	1.6
5. Catapult Launch	6.3
6. Carrier Arrested Landing	5.5
7. High-g Maneuvering (Aerobatics, etc.)	6.8
8. Aerial Combat Maneuvering	31.6

Table II

FLIGHTS BY AIRCRAFT TYPE

Aircraft	Flights
A-6	3
A-7	6
F-14	23
F/A-18	17
S-3	2

6. Testing was conducted on a not-to-interfere basis during operational activities outlined in table III below. A complete synopsis of the actual test flights is included as appendix B.

Table III

TEST MATRIX OVERVIEW

Test Flight	Participating Activity	Primary Test Conditions
1 - 5	NAWC Test Pilots	System Checkout, Flight Ops
6 - 16	NAWC Test Pilots	Day-time Carrier Operations
17 - 30	VF-101	F-14 Aerial Combat Training
31 - 43	VFA-106	F/A-18 Aerial Combat Training
44 - 51	VS-28, VA-37, VF-11, VF-31	Fleet Pilots, Day and Night Carrier Operations

METHOD OF TESTS

7. NAVAIRWARCENACDIV Patuxent River developed a man-mounted, aircraft independent, eight channel digital data instrumentation system. Three test condition parameters, three oxygen system performance parameters, and two recorder integrity monitoring parameters were recorded. Sample rates and parameter ranges are shown in table IV. The recorder provided approximately 14 minutes of actual record time. The recording process could be manually started and stopped and test subjects were instructed to only record data during specified portions of the flight. The instrumentation system consisted of three basic components: a digital recorder, an instrumented CRU-82/P oxygen regulator, and a signal conditioner. The recorder was designed to impose minimal restriction to the breathing effort. Further details of the instrumentation system are included in appendix C.

Table IV

RECORDED PARAMETERS

Parameter	Sample Rate (samples/sec)	Range
Test Condition:		
Forward/Aft Acceleration	5	-8 to +8 Gx
Vertical Acceleration	5	-8 to +8 Gz
Cabin Ambient Pressure	1	0 to 16 PSIA
Oxygen System Performance:		
Regulator Inlet Pressure	10	0 to 128 PSIG
Regulator Outlet Flow	20	0 to 390 LPM ATPD
Regulator Outlet Pressure	10	-10.0 to 15.6 in. H_2O
Recorder Integrity Monitoring:		
Battery Voltage	1	0 to 5 VDC
Signal Conditioner Voltage	1	0 to 5 VDC

8. The data were reduced and analyzed to determine inhalation peak flow rates, breath tidal volume, and breathing rate. More recent guidance for oxygen system performance is provided in the OBOGS design and installation specification (reference 3) and the Air Standardization Coordinating Committee standard for aircrew breathing systems (reference 4). These documents required sinusoidal peak flows of 200 liters/minutes (LPM) altitude temperature, pressure, dry (ATPD). We compared our measured data to the recommended flow rates of reference 3 to ensure the specification is adequate for breathing flow performance requirements.

9. Test subjects were selected at random with an effort to obtain subjects with varying degrees of experience. Each test subject was thoroughly briefed on the objectives of the test, the operating procedure for the recorder, and the desired data points (operating conditions) for recording data. Subjects were freely allowed to decline being a test subject.

10. Data were acquired during 51 flight tests using F/A-18, F-14, A-6, A-7, and S-3 aircraft. Data records were categorized into baseline and eight operational sequences. The total number of breaths measured during each category are listed in table V.

Table V

CATEGORICAL SUMMARY

Condition	Number of Breaths	Contributing Subjects
All Measured Data	11266	41
System Checkout (Base Line)	137	33
Ground Operations/Taxi	269	8
Routine Flight Operations	4351	41
Conventional Take-Off	674	27
Conventional Landing	183	8
Catapult Launch	705	15
Carrier Arrested Landing	619	15
High-g/Acrobatic Maneuvering	771	8
Aerial Combat Maneuvering	3557	22
Total Breaths Measured = 11266 Total Contributing Aircrew Test Subjects = 41 Total Test Flights = 51 (Six subjects flew more than one mission)		

11. The data were analyzed to determine the maximum (peak) oxygen flow during inhalation (LPM, ATPD), the breathing rate in breaths per minute (BPM), and the tidal volume exchange in liters for each breath. These parameters are illustrated in figure 1 for sinusoidal breathing. For each category, the data contributed by each aircrewman were normalized to evenly weight each contributor and not bias the data by any single individual.

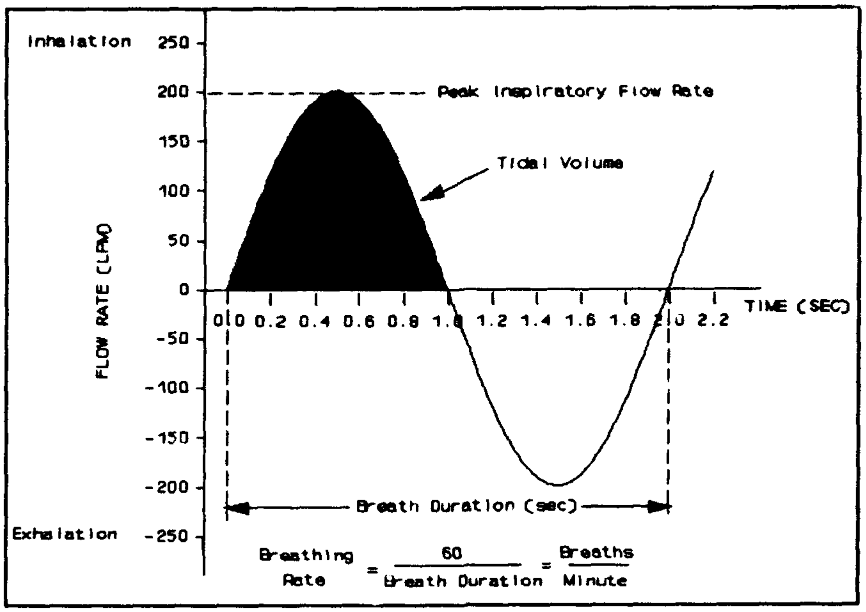

Figure 1
SINUSOIDAL BREATHING AT
200 LPM PEAK FLOW, 30 BPM FREQUENCY

RESULTS AND DISCUSSION

OVERALL DATA TREND

12. The peak inspiratory flow data for each operational condition were analyzed statistically. Histograms of the data distribution for each condition are provided in appendix D. For each category, the data distributions were compared to normal (Gaussian) and lognormal theoretical distributions based on the measured mean and standard deviation. We found that a lognormal statistical distribution provided the best fit for the peak flow data distributions, based on minimizing the error between the theoretical expected frequency of occurrences and actual measured data. Table VI provides a summary of inspiratory peak flow mean and standard deviation calculated for each of the operating conditions. The table also provides the peak flow required to satisfy 90% and 98% of the expected occurrences based on a lognormal distribution. Generally, at least 98% of all peak flows measured (see table VI and figure 1 of appendix D) for this program were within the 200 LPM design guide. The data were then reduced and analyzed for a more detailed evaluation during specific ground and flight operating conditions.

Table VI

PEAK FLOW RATE STATISTICAL ANALYSIS[1]

Condition	Mean (LPM) (ATPD)	STD DEV (LPM) (ATPD)	90% Level[2] (LPM) (ATPD)	98% Level[2] (LPM) (ATPD)
All Measured Data	92	38	143	197
System Checkout (Base Line)	80	39	133	193
Ground Operations/Taxi	59	17	82	102
Routine In-Flight Operations	78	25	112	143
Conventional Take-Off	73	23	104	133
Conventional Landing	74	36	123	178
Catapult Launch	80	26	115	148
Carrier Arrested Landing	76	25	110	141
High-g/Acrobatic Maneuvering	76	23	107	135
Aerial Combat Maneuvering:				
All Data Acquired	125	38	176	223
ACM Subject #23	172	28	209	237
ACM Subject #43	186	44	245	294

[1]Data are presented in volumetric liters per minute (LPM ATPD) and are altitude independent. Actual mass flow will vary with altitude.
[2]Based on a lognormal distribution.

ROUTINE GROUND AND FLIGHT OPERATIONS

13. For routine ground operations (figures 2 and 3 of appendix D), routine flight operations (figure 4 of appendix D), and land-based take-off and landing (figures 5 and 6 of appendix D), at least 98% of the expected occurrences were within the current 200 LPM peak flow requirement. We conclude that the 200 LPM peak flow requirement defined by MIL-D-85520 (reference 3) is adequate for routine ground and flight operations as well as land-based take-offs and landings.

14. Breathing data measured during carrier launch and recovery were acquired using NAVAIRWARCENACDIV Patuxent River test pilots (day operations) and fleet pilots (both day and night operations). Results are provided in figures 7 and 8 of appendix D. Typical breathing patterns for catapult launch and arrested recovery are also shown in figures 9 and 10 of appendix D. For both events, most aircrew experienced slightly higher peak flows just prior and immediately after the event. Our data indicate that most aircrew actually hold their breath during the actual catapult acceleration and arrested deceleration. The high peak flow rates we measured during catapult launch and arrested recovery operations were generally less than 200 LPM peak flow. We conclude that the 200 LPM peak flow requirement defined by MIL-D-85520 (reference 3) is adequate for routine day and night carrier operations. Because testing was generally conducted in fair weather conditions, the data may not be representative of flow rates that would be seen

during inclement weather operations. We recommend that additional in-flight breathing data be acquired during night carrier operations in adverse weather conditions.

HIGH-G/ACROBATIC MANEUVERING NOT INCLUDING AERIAL COMBAT MANEUVERING

15. Breathing data measured during high-g maneuvers (turns, rolls, aerobatics, etc.) are shown in figure 11 of appendix D. The data show reasonable agreement with British Royal Air Force data (reference 5) as shown in figure 12 of appendix D. Previous studies of aircrew breathing efforts (including reference 5) attempted to simulate aerial combat maneuvering (ACM) conditions by having the test subject perform high-g aerobatics. However, results from this project indicate that test subjects performing high-g turns and high-g aerobatics (not associated with ACM) demonstrated lower peak flow rates than subjects engaged in ACM (see discussion in next section). The data suggest that performing high-g aerobatics in a benign environment is not as physically or psychologically demanding as performing ACM. Because of its competitive nature, a subject engaged in ACM is more likely to push himself to his physical limits and thus produce higher breathing flow rates. The 200 LPM peak flow requirement of MIL-D-85520 (reference 3) is adequate for high-g aerobatics. However, high-g aerobatics cannot be used to induce breathing rates comparable to ACM situations as discussed in the next section.

AERIAL COMBAT MANEUVERING

16. The L-1 anti-g straining maneuver is a breathing technique used to increase one's g-tolerance. The L-1 anti-g straining maneuver is characterized by a rapid inhalation of approximately 75-85% of one's maximum inspiratory volume (reference 6). The subject strains against a closed glottis and then performs a rapid, forced exhalation. The L-1 is shown graphically in figure 2.

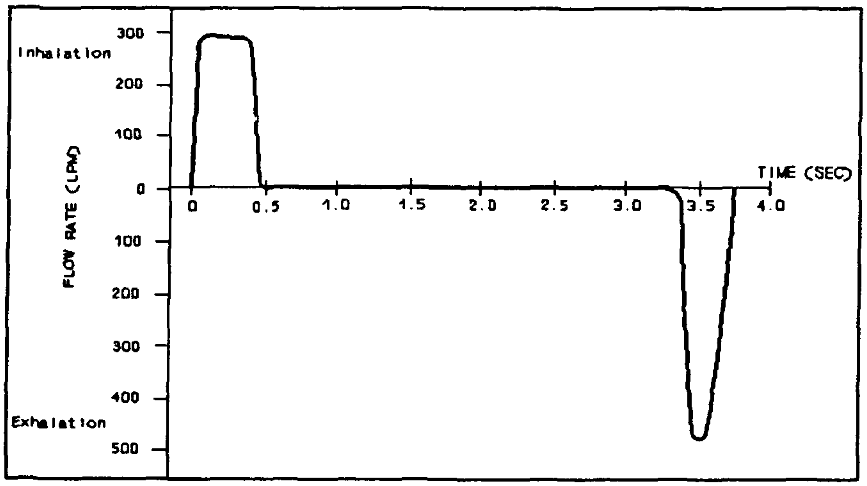

Figure 2
L-1 ANTI-G STRAINING MANEUVER

17. ACM was simulated during training exercises with VF-101 and VFA-106. Breathing data were collected over the entire ACM engagement from the set-up and approach to the post-engagement departure. Typical data are provided in figures 13, 14, and 15 of appendix D. In order to increase his g-tolerance, the pilot will often perform several L-1 anti-g straining maneuvers prior to pulling high-g's (figure 13 of appendix D). Once the aircraft is at a high g-level, the breathing peak flow often decreases possibly due to the acceleration forces on the pilot's lungs and diaphragm. High peak flow rates in excess of 200 LPM are commonly seen immediately following a high-g maneuver as the pilot recovers with rapid, heavy breathing (figure 14 of appendix D). Although this recovery period may last for several minutes following the ACM engagement, the high peak flow rates generally subside within the first 30 seconds to 1 minute. An elevated breathing rate with lower peak flow rates may ensue for several minutes following the encounter before subsiding to a normal rate (figure 15 of appendix D). The results from data measured during ACM indicate that high peak flow rates (in excess of 200 LPM peak flow) may occur before, during, and/or after an ACM engagement.

18. A composite histogram of ACM data from the 22 contributing aircrew is provided in figure 16 of appendix D. Comparing the ACM distribution to the high-g aerobatics (figure 11 of appendix D) indicates that ACM produces significantly higher breathing flow rates than high-g aerobatics. This was attributed to the more physically and psychologically demanding nature of ACM as discussed in paragraph 15. Previous test and evaluation methods have used high-g aerobatics to simulate ACM. Our data, however, verifies that high-g aerobatics in a benign environment do not produce the breathing flow rates comparable to ACM in a competitive environment. (Note the distinct differences in the peak flow distributions overlaid in figure 12 of appendix D.) We conclude that using high-g aerobatics to induce breathing rates comparable to ACM situations is not a valid test and evaluation method.

19. Statistical analysis of the ACM data indicates that 200 LPM peak flow is marginally adequate (figure 16 of appendix D) and will satisfy approximately 95.5% of the expected observations. However, peak flow rates in excess of 200 LPM occur in short "bursts" throughout the ACM engagement. These bursts are a small portion of the entire ACM engagement and tend to become lost (statistically insignificant) when analyzed over the entire ACM engagement (including the set-up and recovery periods, etc.). The tendency to perform statistical analysis on the breathing flow rate data acquired throughout the ACM engagement could lead to the conclusion that the current 200 LPM peak flow requirement is adequate for aircrew flying ACM. Such an analysis, however, would lead to a design standard that is inadequate for the short bursts of high peak flow associated with ACM engagements.

20. Data from two individuals who actively performed anti-g straining maneuvers were given previously in table VI and are shown in figures 17 and 18 of appendix D. These two individuals, who actively perform L-1 anti-g straining maneuvers, frequently produce peak flows that exceed the 200 LPM peak flow recommended by MIL-D-85520. This result is in agreement with breathing flow rate data acquired with NAVAIRWARCENACDIV Warminster's Dynamic Flight Simulator (reference 7), which indicates that a peak flow of 288 LPM ATPD is required to perform the L-1 anti-g straining maneuver (a "coached" L-1 maneuver in a flight simulator). Based on the flow rate data measured during ACM training

and the centrifuge data of reference 7, we conclude that the current 200 LPM peak flow requirement of MIL-D-85520 (reference 3) is inadequate for tactical aircraft performing high-g ACM and needs to be increased.

AIRCRAFT OXYGEN SYSTEM DESIGN

21. Oxygen system test and evaluation requires a consistent and repeatable method for evaluating the response of the system to a dynamic breathing load. The data presented indicate that the highest inspiratory peak flow rates are incurred during ACM. Oxygen systems installed in tactical aircraft should be capable of providing the L-1 anti-g straining maneuver continuously for the duration of the high-g portion of the ACM encounter.

22. The oxygen system must also accommodate the rapid breathing rates and high inspiratory flow rates associated with the recovery period following ACM. The breathing pattern is characterized by variable amplitude inhalation pulses that range from 70 to 300 LPM. Duplicating this pattern on the ground for test and evaluation purposes would require breath by breath control of a mechanical breathing simulator. Although this is possible, it would not be repeatable or easily duplicated from one test activity to another. A sinusoidal wave form is universally understood and easily reproduced. Specifying a sinusoidal flow rate of 260 LPM at sea level conditions would provide the peak inspiratory dynamics to accommodate aircrew performing ACM at altitude. (When adjusted for altitude, 260 LPM peak flow at sea level will provide in excess of 300 LPM peak flow at altitudes above 4,000 feet.) Specifying an associated breathing rate of 43 breaths per minute provides a tidal volume exchange of approximately 1.9 liters, which is not an unrealistic exchange based on the NAVAIRWARCENACDIV Warminster L-1 profile (figure 2). Therefore, for oxygen system design, test, and evaluation, we recommend that MIL-D-85520 be changed to require tactical aircraft oxygen systems be capable of delivering a 260 LPM peak inspiratory flow rate at 43 breaths per minute for a minimum of 3 minutes.

OXYGEN SYSTEM COMPONENT DESIGN

23. Oxygen system components, such as the oxygen mask and regulator, must be capable of providing the peak flow demands experienced during ACM. Most component specifications either specify inadequate dynamic response conditions or none at all. Oxygen mask valves (reference 8) are required to meet steady flow conditions of 100 LPM steady flow for inhalation, 150 LPM for dumping. CRU-79/P oxygen regulators (reference 9) are required to provide 100 LPM steady flow. Previous testing at NAVAIRWARCENACDIV Patuxent River (reference 10) revealed substandard performance of oxygen mask and regulator combinations under dynamic flow conditions. On numerous occasions, the oxygen mask valve would "lock up" during exhalation. This was attributed to high pressure from the oxygen regulator (as it tried to catch up to the rapid onset flow demand) interfering with the oxygen mask valve closure during the forced exhalation period of the L-1 maneuver. While collecting data for this project, discussions with aircrew confirmed numerous instances of mask valve "lock up" in flight during heavy breathing. (These reports referred to their standard oxygen gear, not our instrumentation system.) Therefore, we recommend that the dynamic breathing requirements of 260 LPM peak sinusoidal flow at 43 BPM frequency be incorporated into the oxygen mask valve performance specification (MIL-V-27296B) and the regulator specifications (MIL-R-81553A(AS) and MIL-R-85523(AS)).

ANTI-G STRAINING TECHNIQUE TRAINING

24. During pre- and post-flight interviews, the test subjects were asked if they use any type of anti-g straining maneuver. Responses from this informal survey indicated that only 10% of F-14 and F/A-18 pilots participating in this program commonly practiced an L-1 anti-g straining technique. The majority of the subjects were only vaguely familiar with the L-1 techniques as presented during their quadrennial physiology training. Many of the pilots who do not use straining techniques stated they reduce the g-load on the aircraft when they start to "gray out" rather than performing anti-g straining techniques. It appears that the full benefit of the anti-g straining techniques are not realized by a large percentage of the aircrew. This deficiency has been previously recognized and centrifuge training for tactical aircrew is now required by OPNAVINST 3710.7P.

25. Interviews with test subjects during this project indicated that the aircrew exhibiting enough knowledge to adequately perform the L-1 maneuver had additional face-to-face, one-on-one training on the techniques at some time in their career. At the time, the quadrennial physiology training program only provided a verbal (or video) presentation of the L-1 technique. There were no practice sessions involved. Physiology training is currently being updated to include face-to-face, one-on-one instruction using a computer based breathing rate and characteristic training aid. This training is a lead-in for centrifuge training. Changes to the physiology training program, along with required centrifuge training, will greatly improve the aircrews' awareness of anti-g straining techniques. The increased training will be reflected in higher demands on the oxygen system to meet the dynamic flow requirements of anti-g straining. We recommend continued emphasis on anti-g straining and its benefit in reducing g-induced loss of consciousness.

SEA LEVEL PERFORMANCE

26. Oxygen system components (i.e., oxygen masks, regulators, concentrators, etc.) are mass flow limited. The human breathing system is volume limited. For a constant volumetric demand on the oxygen system (i.e., a constant breathing rate), the mass flow through the system will decrease with altitude due to the reduced ambient air density. Thus, a system that provides adequate volumetric flow at altitude may not be adequate at low altitudes due to the increase in mass flow at low altitudes.

27. Peak volumetric flow rate measurements of aircrew conducting ACM at aircraft altitudes of 10K to 28K feet greatly exceed 200 LPM peak flow. It is unknown if the oxygen system design could provide these same aircrew with adequate mass flow during low altitude ACM (S.L. to 5,000 feet). The noticeable lack of pilot complaints of poor dynamic performance of the aircraft's oxygen system might be attributed to the fact that the majority of ACM training is conducted at 10K to 28K feet aircraft altitude. At these altitudes, the pilot's volumetric flow requirements are the same as at sea level but his mass flow requirements are greatly reduced by the reduced ambient air density. Ground tests on the AV-8B, TAV-8B, T-45, and F/A-18 have been used to evaluate the peak flow capability of the OBOGS under simulated conditions. Example data are provided in figure 19 of appendix D. The capability of the LOX system in the F/A-18 and F-14 aircraft and the OBOGS in the F-14 to provide the flow rates necessary for conducting ACM at low altitude have not been quantitatively tested. Inadequate peak flow capability of the aircraft's oxygen system during low altitude ACM will seriously compromise

the pilot's ability to breath, to communicate (due to the high peak flow rates associated with speech), to perform the anti-g straining maneuver, and to ultimately perform ACM. We recommend that a dynamic breathing performance test of the F-14 aircraft OBOGS and the F-14 and F/A-18 LOX systems be performed to determine the maximum peak flow capability of these systems at sea level conditions.

TIDAL VOLUME/BPM ANALYSIS

28. The data were reduced to determine tidal volume and BPM distributions as described in paragraph 11. For completeness, histograms of the tidal volume distributions are found in appendix D, figures 20 through 29, while BPM distributions are in appendix D, figures 30 through 39. A statistical analysis indicates that, while tidal volume is best modeled by a lognormal distribution, BPM is best modeled by a normal distribution. The calculated mean and standard deviation for each category is summarized in table VII. Although not significantly different, the data do show a trend of increasing tidal volume and BPM with increasing workload from ground operations to flight operations, carrier launch and recovery, high-g maneuvering, and ACM. Not evident within the statistical averages are the typical exaggerated breaths measured immediately prior to catapult launch (figure 9 of appendix D) and carrier arrested landing (figure 10 of appendix D). These breaths tended to be deeper and slower than normal. These breaths are typically of low peak flow amplitude and should thus be satisfied by the ACM required peak flow rates.

Table VII

TIDAL VOLUME AND BPM BY CATEGORY

			Tidal Volume (Liters)			
Conditions	No. Obs.	No. Air-crew	Mean	STD DEV	90% Level[1]	98% Level[1]
All Measured Data	11266	41	1.47	0.82	2.57	3.95
System Check (Base Line)	137	33	1.89	0.98	3.21	4.78
Ground Operations/Taxi	269	8	1.18	0.48	1.83	2.50
Routine In-Flight Operations	4351	44	1.49	0.80	2.56	3.88
Conventional Take-Off	674	27	1.63	0.91	2.85	4.38
Conventional Landing	183	8	1.14	0.54	1.87	2.69
Catapult Launch	705	15	1.36	0.69	2.29	3.38
Carrier Arrested Landing	619	15	1.41	1.03	2.75	4.83
High-g Acrobatic Maneuvering	771	8	1.17	0.64	2.03	3.09
Aerial Combat Maneuvering	3557	22	1.96	0.92	3.20	4.60

[1]Based on a lognormal distribution.

			Breaths Per Minute			
Conditions	No. Obs.	No. Air-crew	Mean	STD DEV	90% Level[1]	98% Level[1]
All Measured Data	11266	41	20.4	9.8	32.9	40.5
System Check (Base Line)	137	33	14.5	5.7	21.8	26.2
Ground Operations/Taxi	269	8	17.0	5.6	24.2	28.5
Routine In-Flight Operations	4351	44	17.5	7.9	27.6	33.7
Conventional Take-Off	674	27	15.6	8.7	26.7	33.4
Conventional Landing	183	8	18.3	7.3	27.6	33.3
Catapult Launch	705	15	19.4	8.0	29.6	35.8
Carrier Arrested Landing	619	15	20.7	7.9	30.8	36.9
High-g Acrobatic Maneuvering	771	8	24.4	10.2	37.5	45.3
Aerial Combat Maneuvering	3557	22	21.6	11.6	36.5	45.4

[1]Based on a normal distribution.

THIS PAGE INTENTIONALLY LEFT BLANK

CONCLUSIONS

GENERAL

29. The data collected for this project generally show good correlation with previous studies. The data base provides unique results for carrier operations and ACM conditions not previously reported.

30. The breathing requirement specifications for LOX and OBOGS equipped aircraft are inadequate for breathing rates measured during high workload ACM in tactical aircraft.

SPECIFIC

31. The 200 LPM peak flow requirement defined by MIL-D-85520 (reference 3) is adequate for routine ground and flight operations as well as land-based take-offs and landings (paragraph 13).

32. The 200 LPM peak flow requirement defined by MIL-D-85520 (reference 3) is adequate for routine day and night carrier operations (paragraph 14).

33. The 200 LPM peak flow requirement of MIL-D-85520 (reference 3) is adequate for high-g aerobatics (paragraph 15).

34. High peak flow rates (in excess of 200 LPM peak flow) may occur before, during, and/or after an ACM engagement (paragraph 17).

35. Using high-g aerobatics to induce breathing rates comparable to ACM situations is not a valid test and evaluation method (paragraph 18).

36. The current 200 LPM peak flow requirement of MIL-D-85520 (reference 3) is inadequate for tactical aircraft performing high-g ACM (paragraph 20).

37. Changes to the physiology training program, along with required centrifuge training, will greatly improve the aircrews' awareness of anti-g straining techniques. The increased training will be reflected in higher demands on the oxygen system to meet the dynamic flow requirements of anti-g straining (paragraph 25).

RECOMMENDATIONS

38. Acquire additional in-flight breathing data during night carrier operations in adverse weather conditions (paragraph 14).

39. Install tactical aircraft oxygen systems that are capable of providing the L-1 anti-g straining maneuver continuously for the duration of the high-g portion of the ACM encounter (paragraph 21).

40. Change MIL-D-85520 to require tactical aircraft oxygen systems to be capable of delivering a 260 LPM peak inspiratory flow rate at 43 breaths per minute for a minimum of 3 minutes (paragraph 22).

41. Incorporate the dynamic breathing requirements of 260 LPM peak sinusoidal flow at 43 BPM frequency into the oxygen mask valve specification (MIL-V-27296B) and the regulator specifications (MIL-R-81553A(AS) and MIL-R-85523(AS)) (paragraph 23).

42. The anti-g straining technique and its benefit in reducing g-induced loss of consciousness should continue to be emphasized through quadrennial physiology training and mandatory centrifuge training for TACAIR aircrew (paragraph 25).

43. Perform a dynamic breathing performance test of the F-14 aircraft OBOGS and the F-14 and F/A-18 LOX systems to determine the maximum peak flow capability of these systems at sea level conditions (paragraph 27).

REFERENCES

1. AIRTASK A531531A/053-D/6W06060000, WUA A-5311B-R6, of 5 Sep 1985.

2. NAVAIRWARCENACDIV Warminster WUA N62269/93/WX/0006 of 3 Dec 1992.

3. Military Specification MIL-D-85520, Design and Installation of On Board Oxygen Generating Systems in Aircraft, General Specification for, of 10 Mar 1983.

4. ASCC AIR STD 61/22, Air Standardization Coordinating Committee, of 18 Aug 1982.

5. "In-flight Breathing Responses in High Performance Aircraft", 1983 Annual Scientific Meeting, Aerospace Medical Association, 23-26 May 1983.

6. "Effect of Inspiratory Volume on Intrathoracic Pressure Generated by an L-1 Maneuver", Aviation, Space, and Environmental Medicine, Nov 1986.

7. "F/A-18 Breathing System Analysis, Phase II - Breathing Requirements Evaluation", NAVAIRDEVCEN Report # NADC-87061-60 (not formally released, information provided by NAVAIRWARCENACDIV Warminster Code 6023).

8. Military Specification MIL-V-27296B, Valve, Oxygen Mask, Combination Inhalation and Exhalation, of 25 Jul 1983.

9. Military Specification MIL-R-81553A(AS), Regulator, Chest Mounted, 100 Percent Oxygen, Positive Pressure, CRU-79/P, of 16 Jul 1990.

10. NAVAIRTESTCEN Technical Report SY-74R-87, "F/A-18A High-G Loss of Consciousness Oxygen System Component Evaluation", of 24 May 1988.

THIS PAGE INTENTIONALLY LEFT BLANK

DATA CATEGORY DESCRIPTION

Category	Description
System Checkout (Base Line)	Once the test subject was situated in the aircraft and the final connections made, the subject was asked to take one short record (2 or 3 breaths) to confirm operation of the recorder and breathing gas system. Test subjects generally took slow, deep, exaggerated breaths to get a feel for the response of the system.
Ground Operations/Taxi	Data acquired during taxi and other ground operations that do not include take-off or landing rolls.
Routine In-Flight Operations	Test subjects performing routine in-flight operations such as navigation, formation flying, idle power descents, etc.
Conventional Take-Off	Test subjects were instructed to start record just prior to take-off roll and to stop record approximately 30 seconds after take-off. These records are normally 45 to 60 seconds in duration.
Conventional Landing	Test subjects performing land based landings.
Catapult Launch	Test subjects were instructed to start record approximately 15 seconds prior to launch and to stop record approximately 20 to 30 seconds after becoming airborne.
Carrier Arrested Landing	Test subjects performing carrier landings during both day and night operations.
High-g Maneuvering	Test subjects performing airborne maneuvers in excess of 3-g or aerobatics. This category includes hard turns and "breaks" but does not include maneuvers during aerial combat maneuvering.
Aerial Combat Maneuvering	Data acquired during ACM training exercises. ACM includes 1V1, 2V1, 1V2, and 2V2 situations. Only ACM data at elevated g-levels were accepted in this category.

THIS PAGE INTENTIONALLY LEFT BLANK

TEST MATRIX SUMMARY

Flight	Aircraft Type	Aircrew	Experience Level	Flight Summary
1	F/A-18A	Pilot	TP	6 Catapults (land based)
2	A-7	Pilot	TP	Bombing runs, high-g maneuvering
3	A-6	B/N	TP	Bombing runs, ship attack
4	A-7	Pilot	TP	Catapult (land based), FCLP's
5	A-7	Pilot	TP	High-g maneuvers, aerobatics

Carrier Launch and Recovery, Day-Time, USS ROOSEVELT (CVN-71)

Flight	Aircraft Type	Aircrew	Experience Level	Flight Summary
6	F/A-18	Pilot	TP	1 catapult, 1 trap
7	A-7	Pilot	TP	2 catapults, 2 traps
8	F-14	Pilot	TP	1 catapult
9	F-14	Pilot	TP	2 catapults, high-g turns
10	A-6	Pilot	TP	1 catapult, 1 trap, 2 wave offs
11	A-6	Pilot	TP	2 touch & go, 1 trap, high-g
12	F/A-18	Pilot	TP	1 trap
13	F/A-18	Pilot	TP	1 catapult, 1 trap, high-g turns
14	F-14	Pilot	TP	4 catapults, 4 traps
15	F-14	NFO	TP	2 catapults, 3 traps
16	F-14	NFO	F-EX	2 catapults, 2 traps, 2 high-g turns

F-14 Aerial Combat Training, NAS Key West, VF-101

Flight	Aircraft Type	Aircrew	Experience Level	Flight Summary
17	F-14	Pilot	F-IP	gunnery run, air intercept
18	F-14	Pilot	F-IP	high-g turns, aerobatics, ACM demo
19	F-14	Pilot	F-IPT	(3) 1 v 1 ACM
20	F-14	Pilot	F-SP	(3) 1 v 1 ACM
21	F-14	Pilot	F-SP,T	(2) 1 v 1 ACM, high-g turns
22	F-14	NFO	F-SN	(3) 2 v 2 ACM
23	F-14	Pilot	F-SP,T	(1) 1 v 1 ACM
24	F-14	Pilot	F-SP	(4) 1 v 1 ACM
25	F-14	Pilot	F-SP	(1) 1 v 1 ACM
26	F-14	Pilot	F-SP	(3) 1 v 1 ACM
27	F-14	NFO	F-SN	Straight & Level Flight
28	F-14	NFO	F-SN	(1) 1 v 1 ACM
29	F-14	Pilot	F-IP	(1) 1 v 1 ACM
30	F-14	NFO	F-SN	(3) 1 v 1 ACM

F/A-18A Aerial Combat Training, NAS Key West, VFA-106

31	F/A-18	Pilot	F-IP	(2) 1 v 1, (1) 1 v 1 v 1 ACM
32	F/A-18	Pilot	F-IP	(4) 2 v 1 ACM
33	F/A-18	Pilot	F-IP	(1) 1 v 1 ACM
34	F/A-18	Pilot	F-IP	(4) 2 v 2 ACM
35	F/A-18	Pilot	F-IP	(4) 1 v 1 ACM
36	F/A-18	Pilot	F-IP	(2) 2 v 2 ACM
37	F/A-18	Pilot	F-SP	(3) 2 v 2 ACM
38	F/A-18	Pilot	F-SP	(3) 2 v 2 ACM
39	F/A-18	Pilot	F-IP	(2) 2 v 2, (1) 1 v 1 ACM
40	F/A-18	Pilot	F-SP,T	(3) 2 v 2 ACM
41	F/A-18	Pilot	F-SP,T	(3) 2 v 2 ACM
42	F/A-18	Pilot	F-SP	Straight & Level Flight
43	F/A-18	Pilot	F-SP	(1) 1 v 1 ACM

Fleet Aircrew, Carrier Launch and Recovery, USS SARATOGA (CV-60)

44	S-3	NFO	F-EX	2 catapults, 2 traps, Night CQ
45	F-14	Pilot	F-NP	4 catapults, 4 traps, Day CQ
46	F-14	Pilot	F-EX	4 catapults, 2 traps, Night CQ
47	A-7	Pilot	F-EX	2 air intercepts
48	F-14	Pilot	F-EX	3 catapults, 3 traps, Day CQ
49	S-3	Pilot	F-NP	low altitude surface search at night
50	A-7	Pilot	F-NP	3 catapults, 5 traps, Day CQ
51	F-14	Pilot	F-NP	2 ACM passes, 3 bolters poor weather

Experience Level:

TP:	Test Pilot	-	U.S. Navy Test Pilot School graduate, well experienced in aircraft type
F-EX:	Fleet Aircrew	-	well experienced in aircraft type
F-IP:	Fleet Aircrew	-	Instructor Pilot, well experienced in aircraft type
F-IPT:	Fleet Aircrew	-	Instructor Pilot in Training, well experienced in type
F-SP:	Fleet Aircrew	-	Student Pilot, limited experience in aircraft type
F-SP,T:	Fleet Aircrew	-	Student Pilot, Transitioning from other aircraft type
F-SN:	Fleet Aircrew	-	Student NFO, limited experience in aircraft type
F-NP:	Fleet Aircrew	-	New Pilot, new pilot in squadron, limited time in aircraft type

INSTRUMENTATION SYSTEM

SYSTEM

1. The instrumentation system used to acquire breathing and aircraft positional data is a man-mounted, aircraft independent, battery operated, eight channel, programmable, digital recorder with an instrumented CRU-82/P oxygen regulator and associated signal conditioner. The components are shown in figure 1.

RECORDER

2. The digital data recorder included a Z-80 microprocessor, analog to digital converter, 16 character alpha-numeric keypad, and 24 character by 3 line liquid crystal display for user queuing and prompting instructions. Sampling rates could be varied from 1 to 200 samples/second/channel. With power on, the record process could be started and stopped to conserve memory for the desired test point. The recorder was later modified with a raised toggle switch to facilitate record starting and stopping during night operation. The recorder was uploaded with test identification information and channel sampling requirements using a personal type computer. Postflight data were downloaded, reduced, and analyzed using the same computer. The recorder was worn on the aircrew's left thigh and held in place with two standard knee-board straps and an additional strain relief strap that looped through the aircrew's torso harness for added stability during walking (preflight) and carrier arrested landing.

INSTRUMENTED REGULATOR

3. The CRU-82/P oxygen regulator was designed for use with the OBOGS but may also be used on aircraft with LOX systems. The CRU-82/P exhibits superior flow characteristics and is capable of sustaining a positive outlet pressure during sinusoidal peak flow rates in excess of 450 LPM. The objective of the instrumentation system was to measure unrestricted breathing efforts during all phases of flight. A restrictive breathing gas source would tend to reduce peak flow rates and distort flow wave forms. Breathing data measured without any type of oxygen mask would be ideal. However, NATOPS requirements and safety considerations prevented having the test subject fly above 10,000 feet without oxygen or with a 100% oxygen enriched cockpit. Therefore, the CRU-82/P oxygen regulator provided the best option for providing an "unrestricted" oxygen supply without denying the aviator oxygen breathing gas. Subsequent laboratory testing (NAVAIRWARCENACDIV Patuxent River Report SY-74R-87) evaluated the oxygen mask cavity pressure as a function of oxygen regulator outlet pressure. Results from that series of testing indicate that, for peak flow rates less than 390 LPM ATPD, the CRU-82/P oxygen regulator will maintain a positive pressure within the MBU-14/P oxygen mask cavity. Therefore, it can be concluded that, for peak flow rates less than 390 LPM ATPD measured in-flight, the oxygen mask cavity pressure remained positive and the test subject was provided an unrestricted oxygen source.

4. To facilitate maximum flexibility in choosing test subjects during remote site testing, the test subject aviators were allowed to use their own personal oxygen masks. Prior to flight, the test subject's personal oxygen mask was attached to instrumented CRU-82/P oxygen regulator and oxygen hose. The CRU-82/P regulator was held by velcro and snaps to a cummerbund type strap that looped

through the aircrew's torso harness. This mounting retained the flexibility of mounting the instrumented regulator to the aircrew without modifying his torso harness.

5. The CRU-82/P oxygen regulator was instrumented with pressure transducers on the oxygen high pressure inlet and low pressure outlet. A laminar flow element was modified to attach to the outlet of the regulator. The pressure drop through the laminar flow element was calibrated against known dynamic flows generated by a Variable Profile Breathing Simulator (VPBS). Pressure transducers were mounted perpendicular to the Gz axis to minimize the effects of positive and negative acceleration on flow measurements.

SIGNAL CONDITIONER

6. The signal conditioner provided instrumentation supply voltage and data signal conditioning for the system's transducer. The signal conditioner was normally placed in the aircrew's pistol pocket (upper left pocket on the torso harness) or in the cavity behind the torso harness zipper.

AIRCRAFT/AIRCREW COMPATIBILITY

7. An aircrewman wearing the instrumentation system is shown in figure 2. Prior to first flight, the Aircrew Systems Escape and Survivability Section evaluated the instrumentation system and determined the system did not impose additional hazards for emergency egress. Additionally, the system was measured for electromagnetic emission. No abnormal emissions were detected and it was determined that the instrumentation system would not interfere with any of the aircraft electronic equipment. Physical weight characteristics are shown below:

Component	Weight	
Recorder w/knee-board straps:	1278 grams	
Regulator w/cummerbund:	937 grams	
Signal Conditioner w/connectors:	344 grams	

Total Recording System Weight:	2559 grams	
CRU-79/P Regulator w/case:	371 grams	
Delta Weight Growth for Recording System:	2188 grams	(4.8 lb)

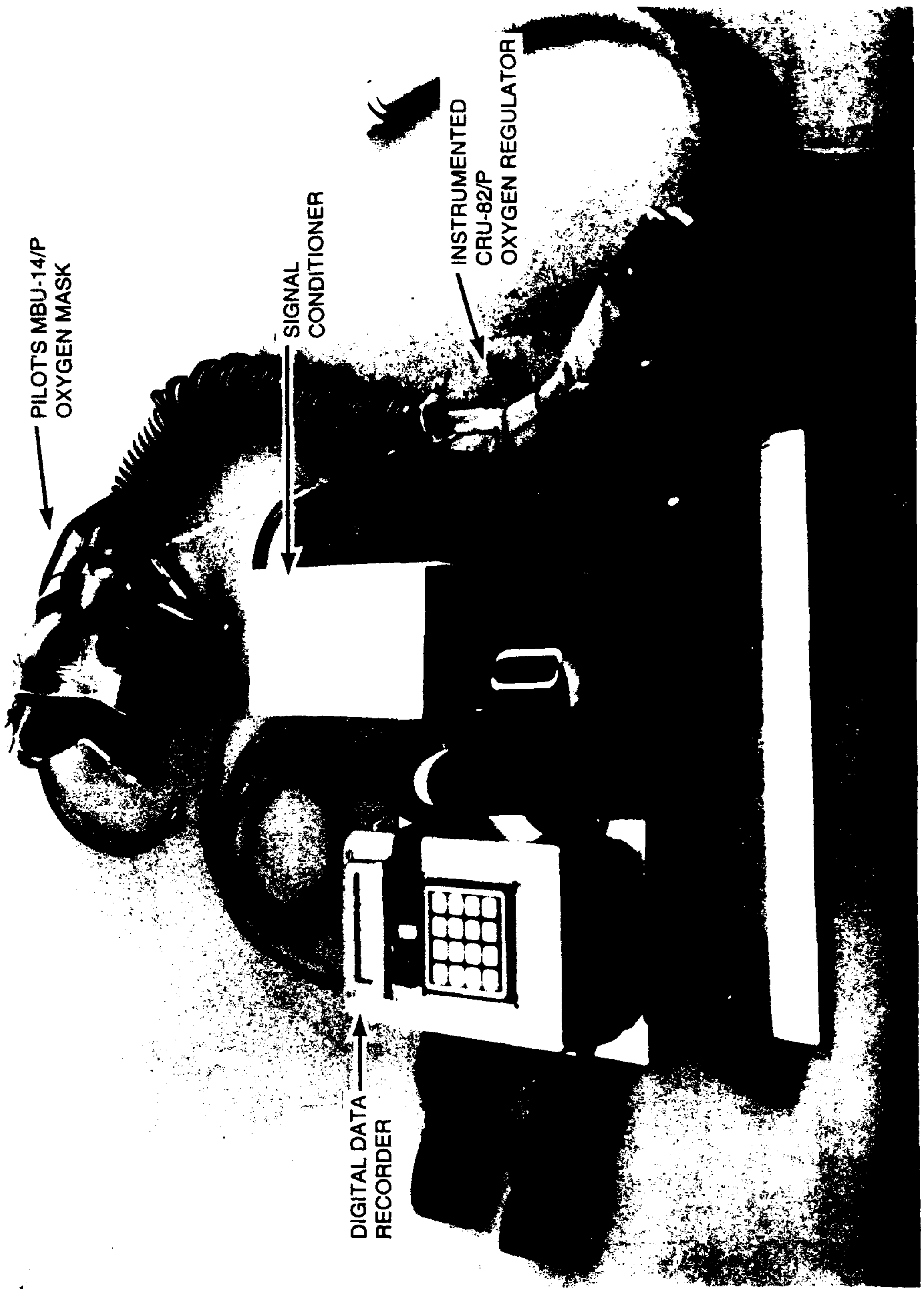

Figure 1
RESPIRATORY DATA ACQUISITION PROGRAM INSTRUMENTATION SYSTEM

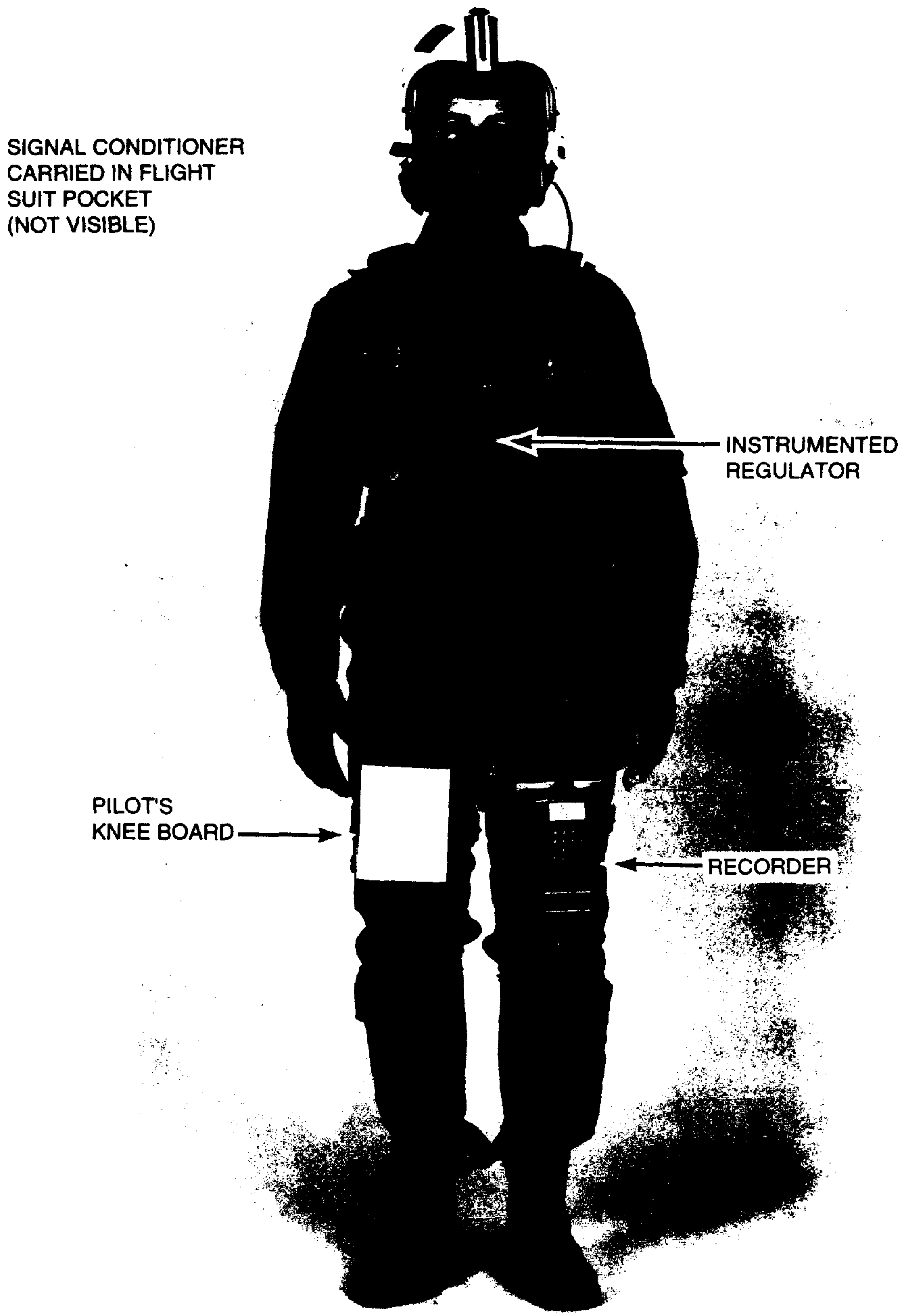

Figure 2
PILOT WEARING INSTRUMENTATION SYSTEM

SAMPLE RESPIRATORY DATA AND HISTOGRAMS

LIST OF FIGURES

No. Figure Title

<u>Breaths Per Minute Data</u>

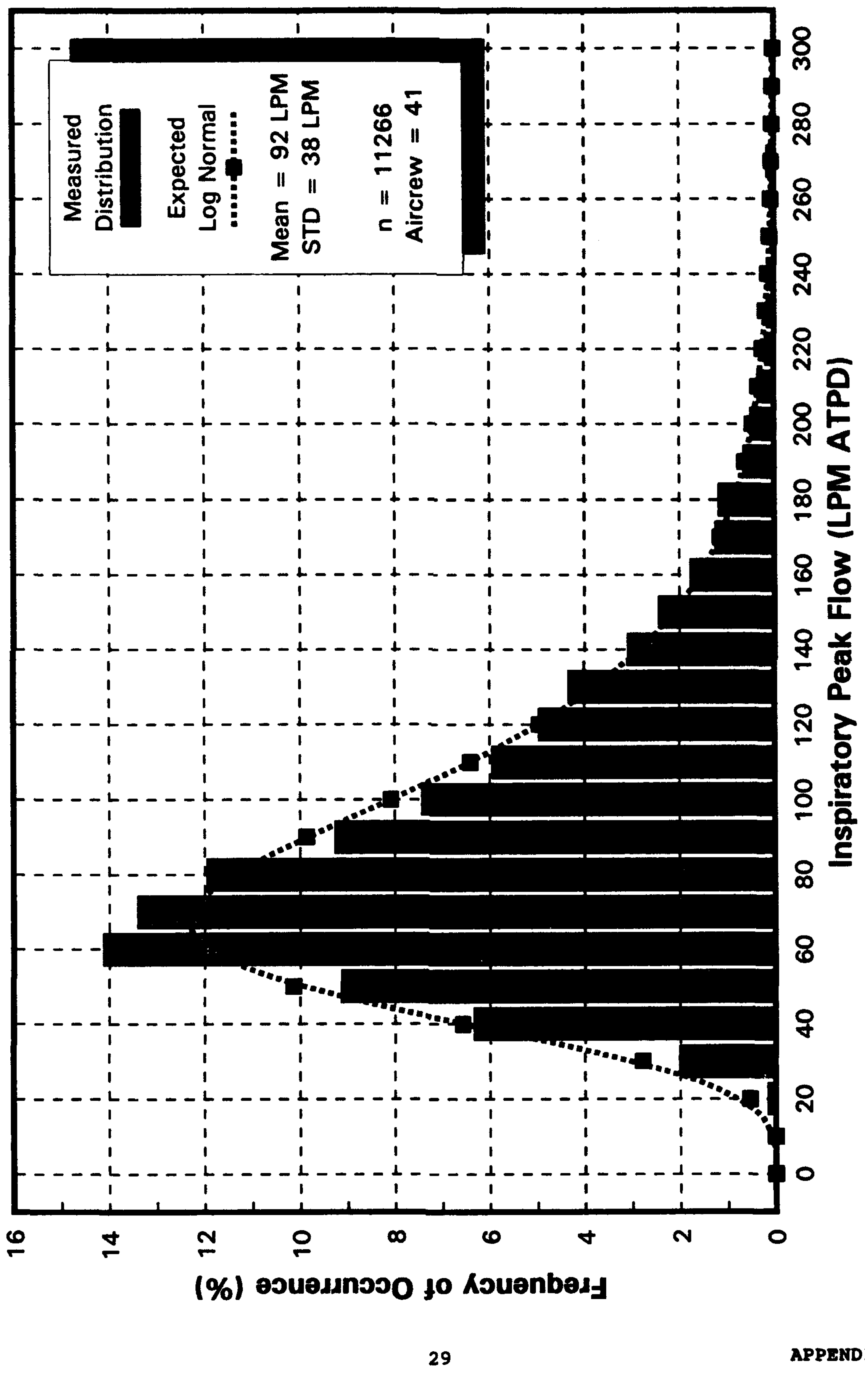

Figure 1
Peak Flow Distribution of All Measured Data

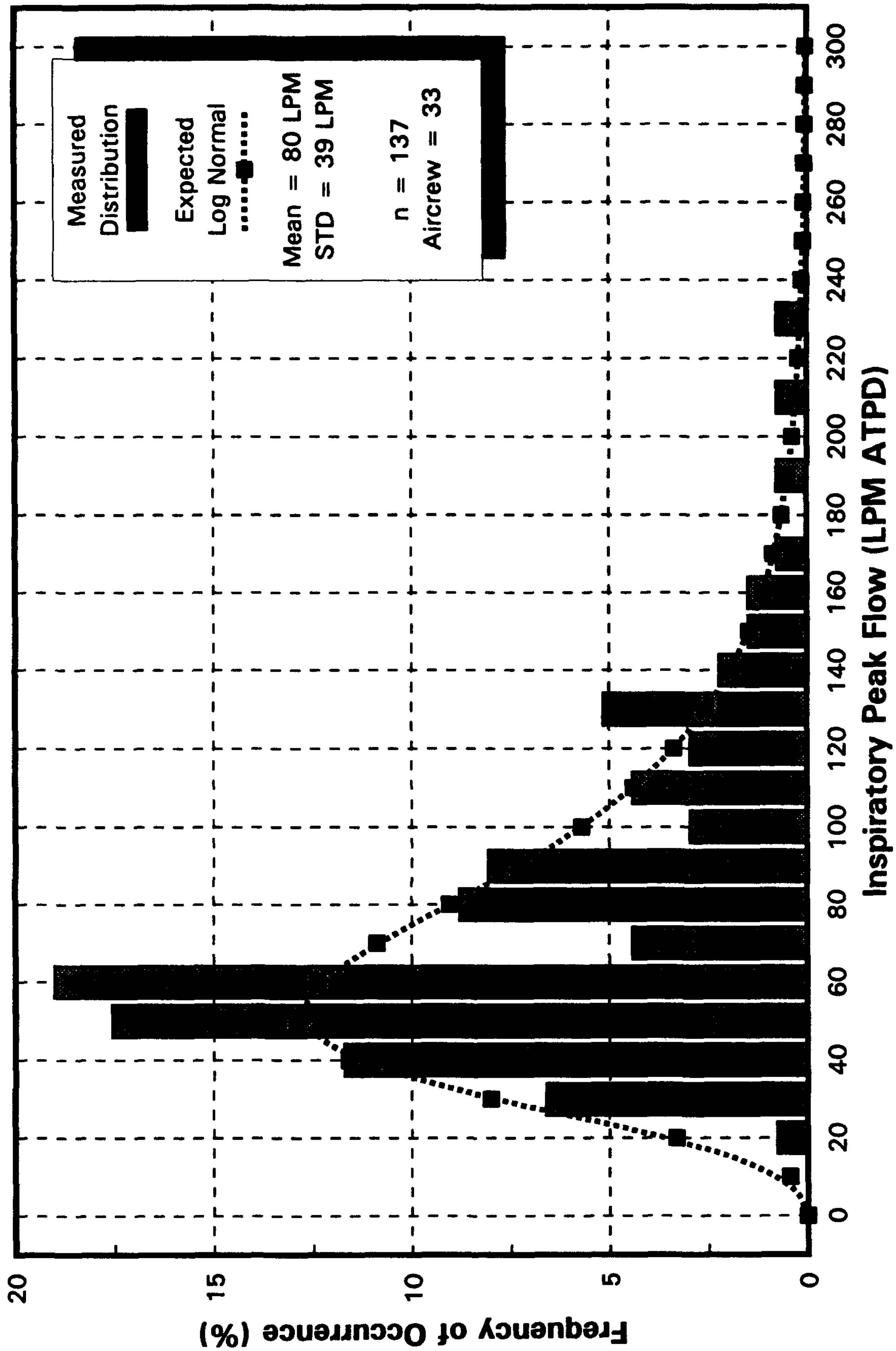

Figure 2
Peak Flow Distribution During System Checkout

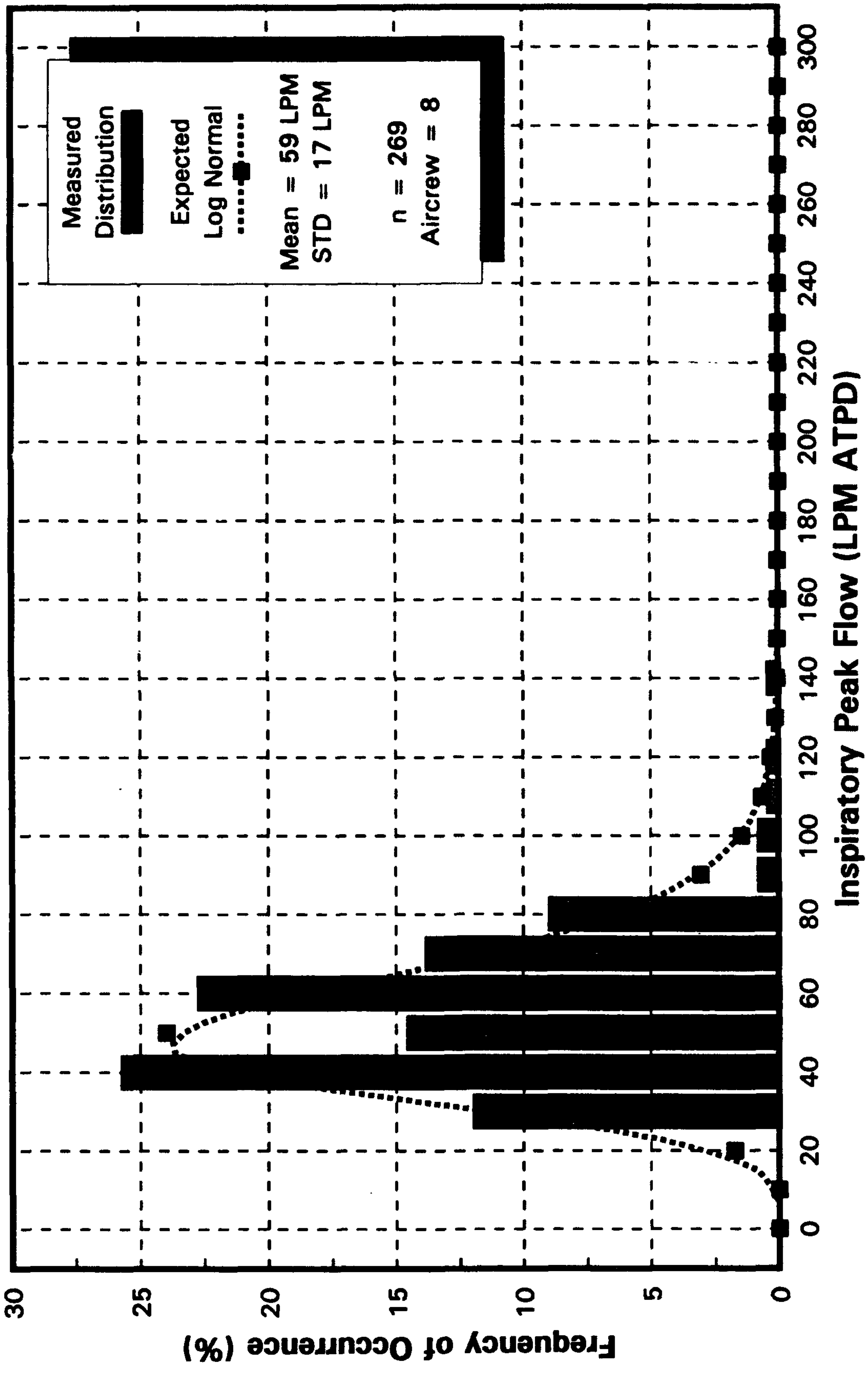

Figure 3
Peak Flow Distribution During
Ground Operations/Taxi

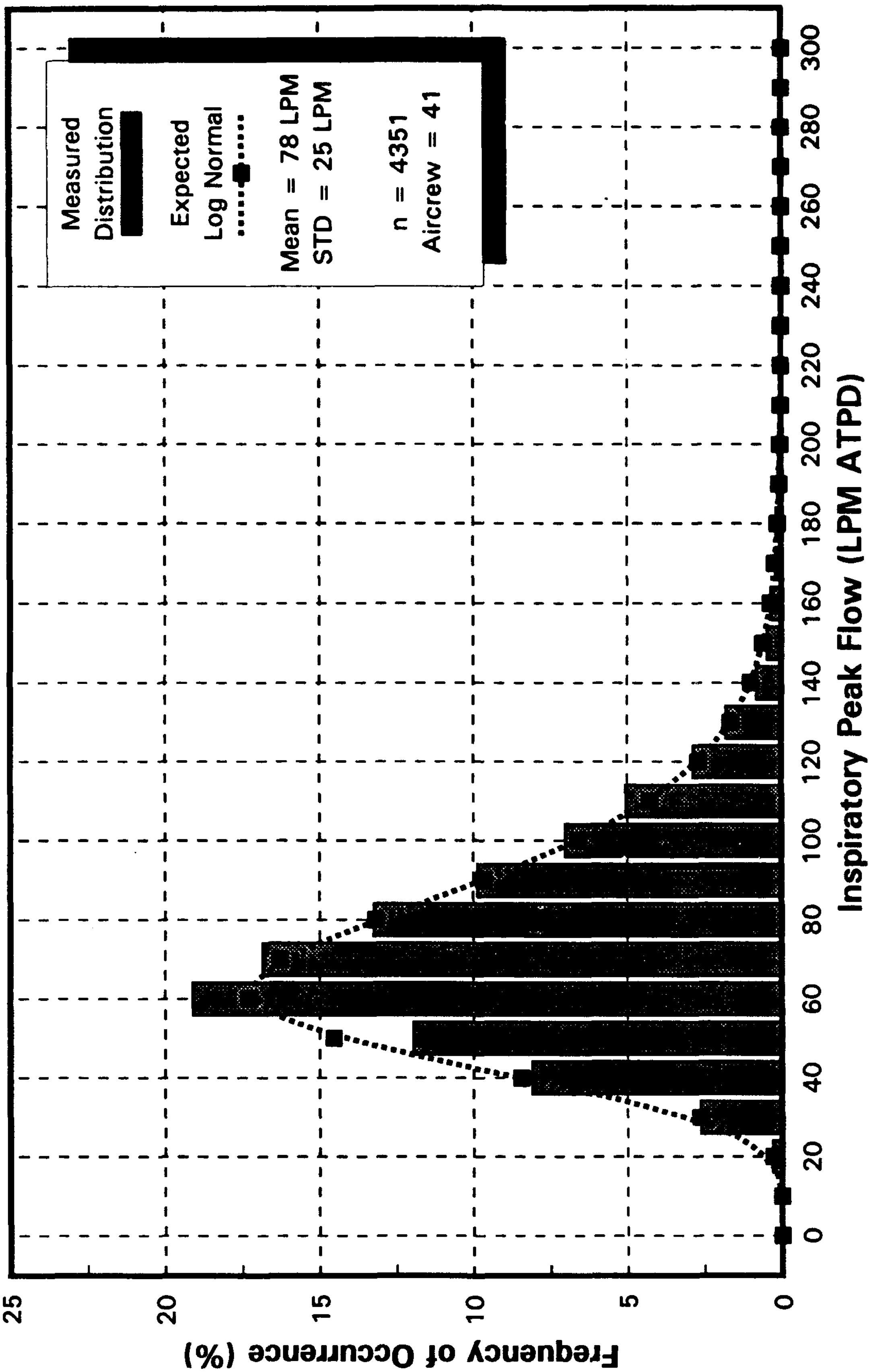

Figure 4
Peak Flow Distribution During
Routine In-Flight Operations

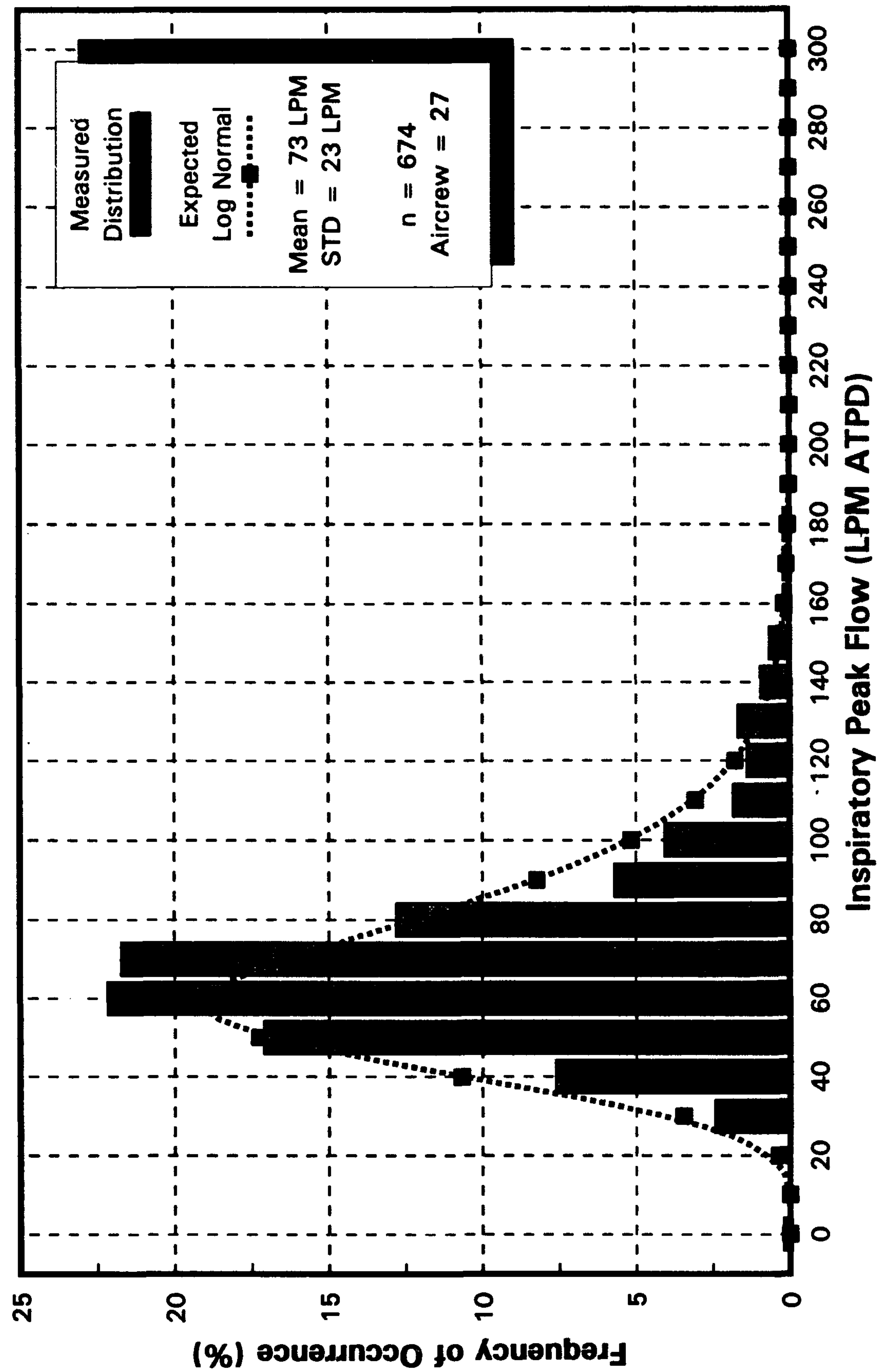

Figure 5
Peak Flow Distribution During
Conventional (Land Based) Take Off

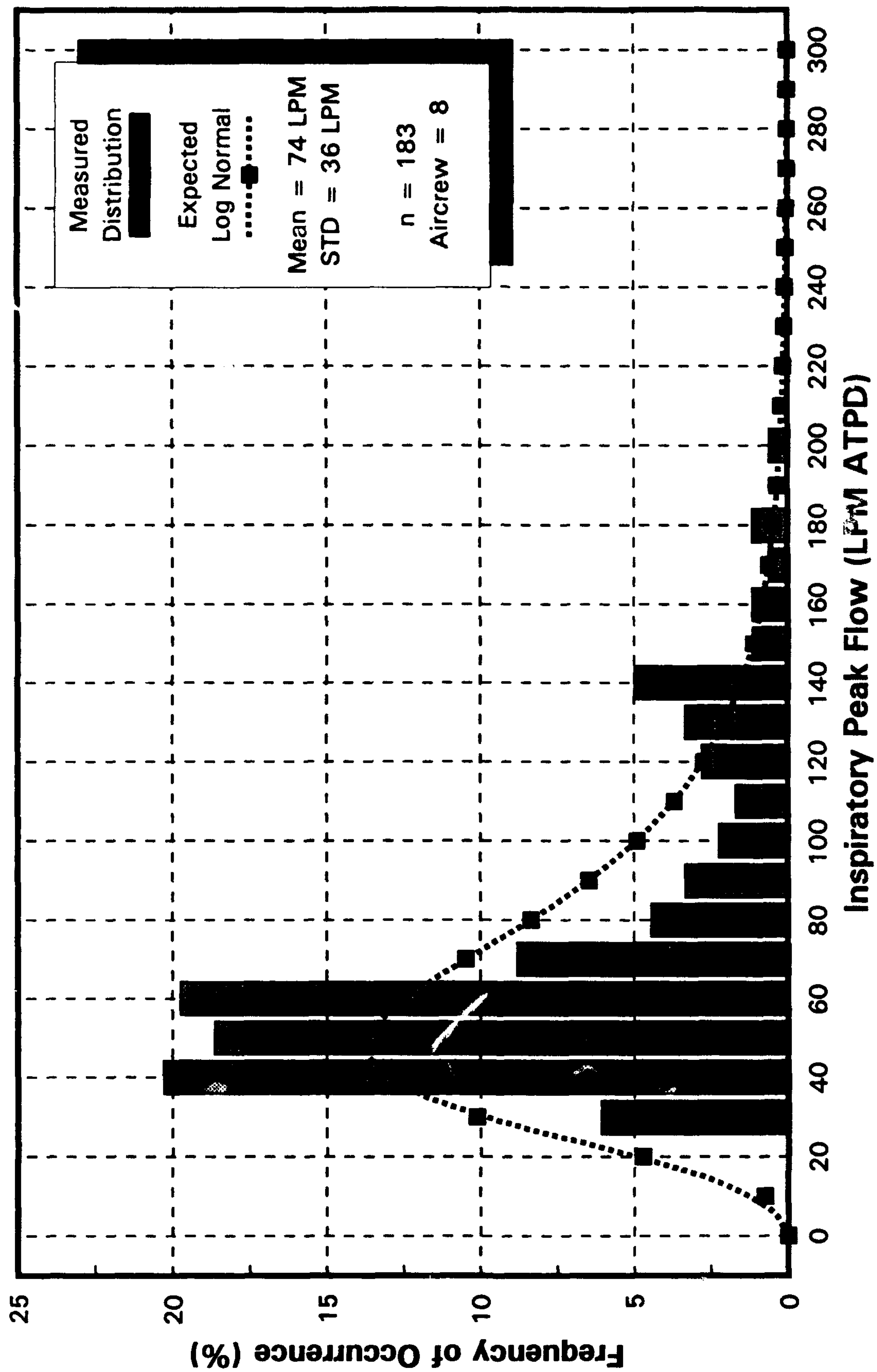

Figure 6
Peak Flow Distribution During
Conventional (Land Based) Landing

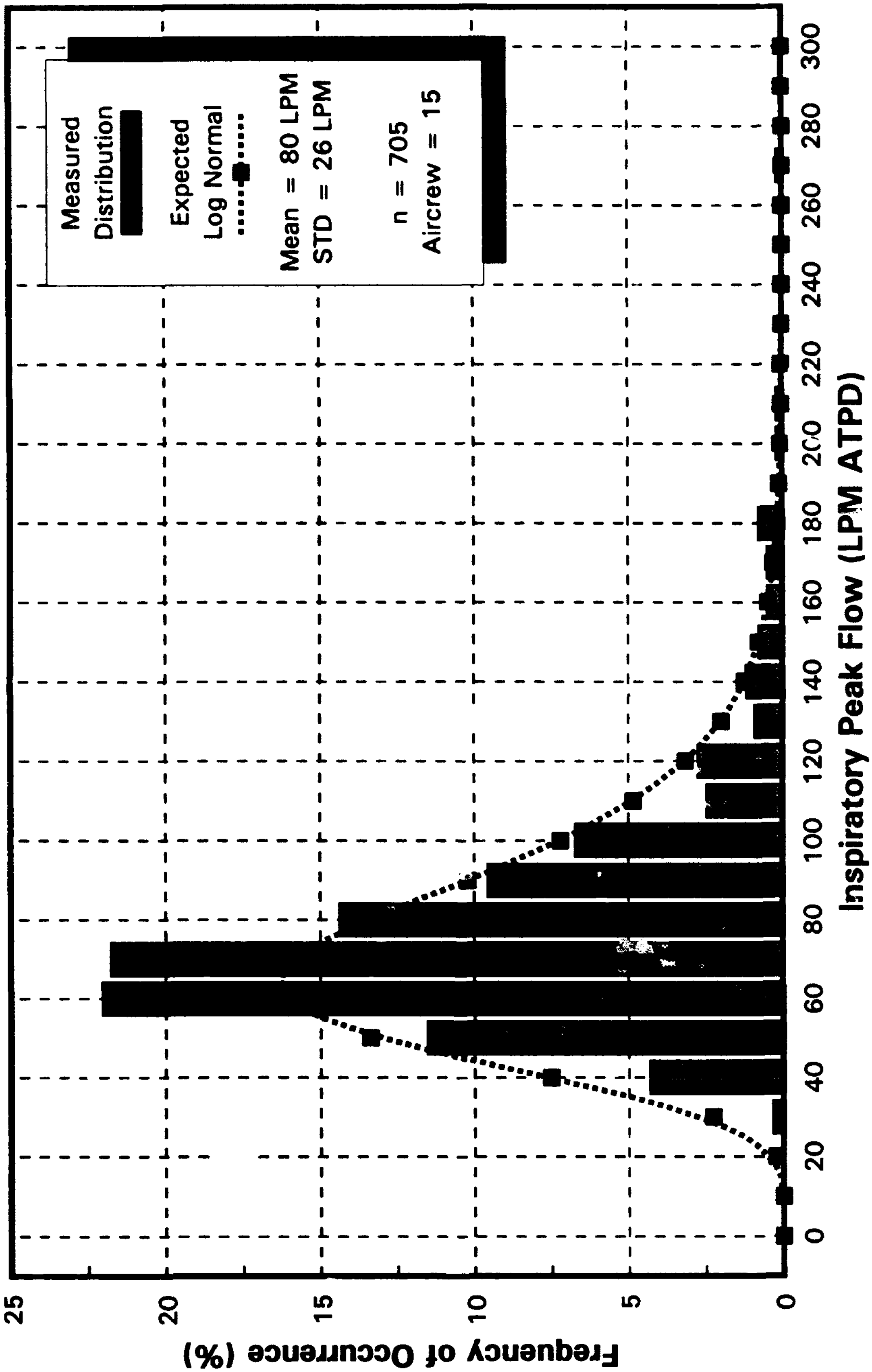

Figure 7
Peak Flow Distribution During Catapult Launch

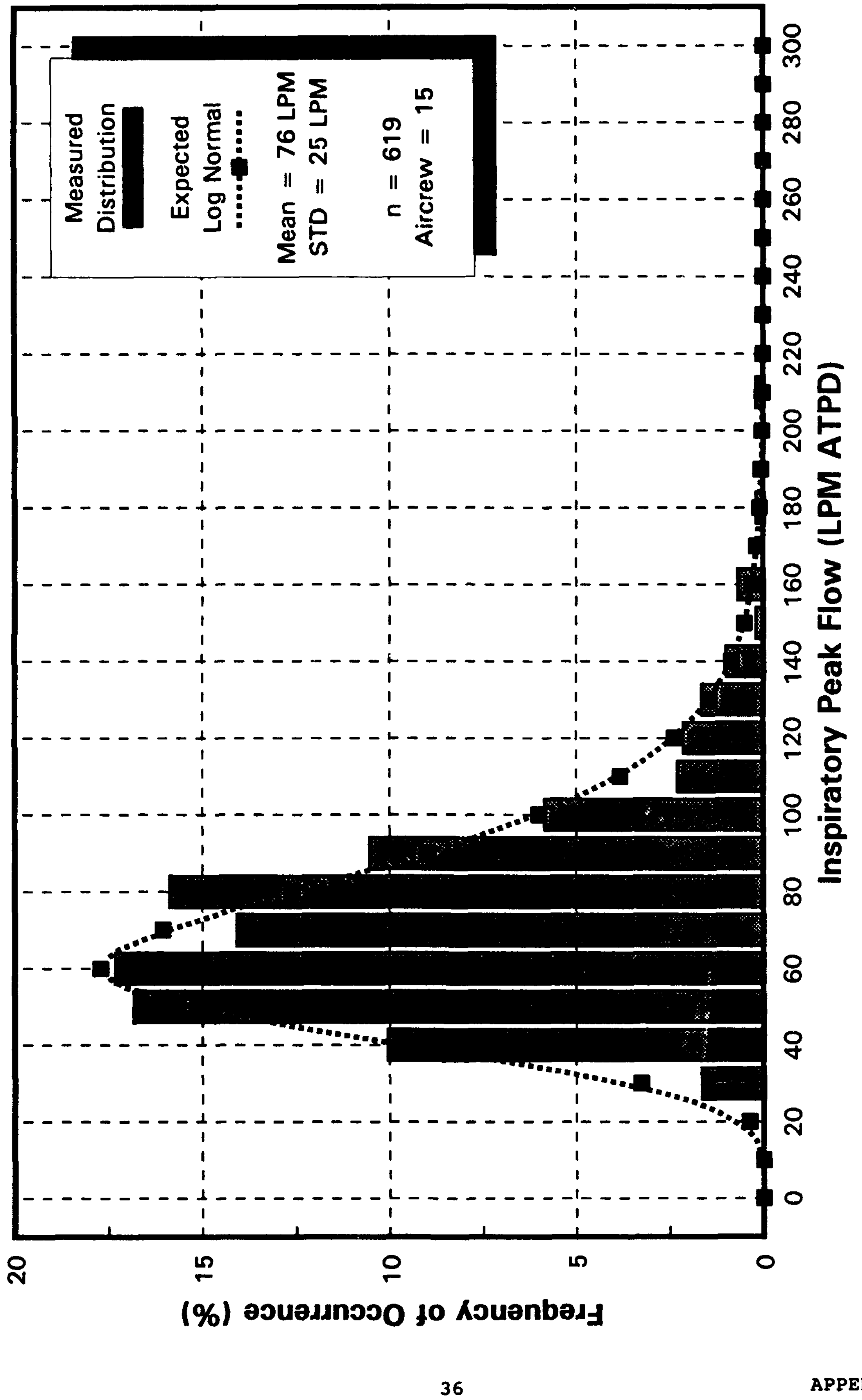

Figure 8
Peak Flow Distribution During
Carrier Arrested Landing

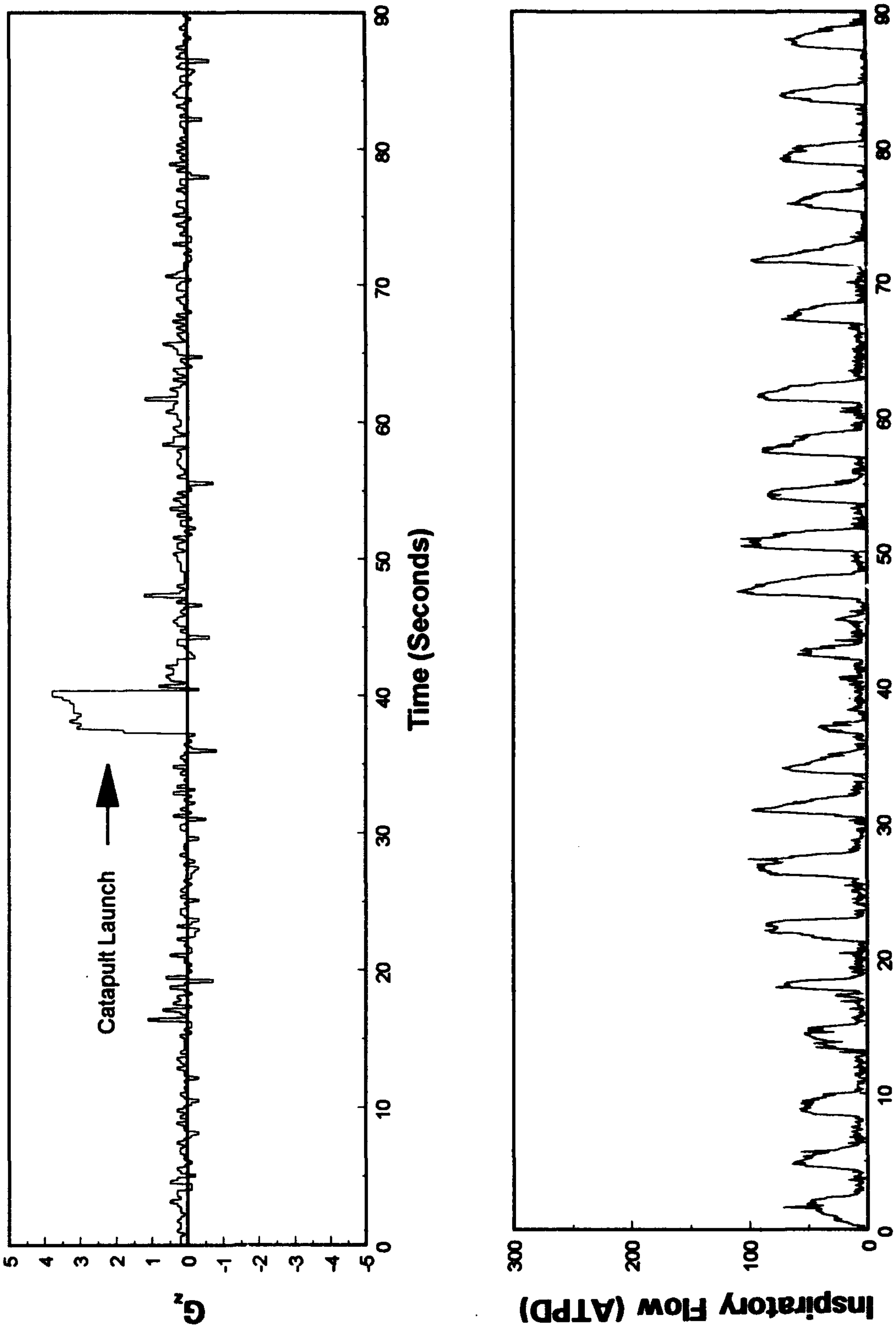

Figure 9
Typical Breathing Flow During Catapult Launch

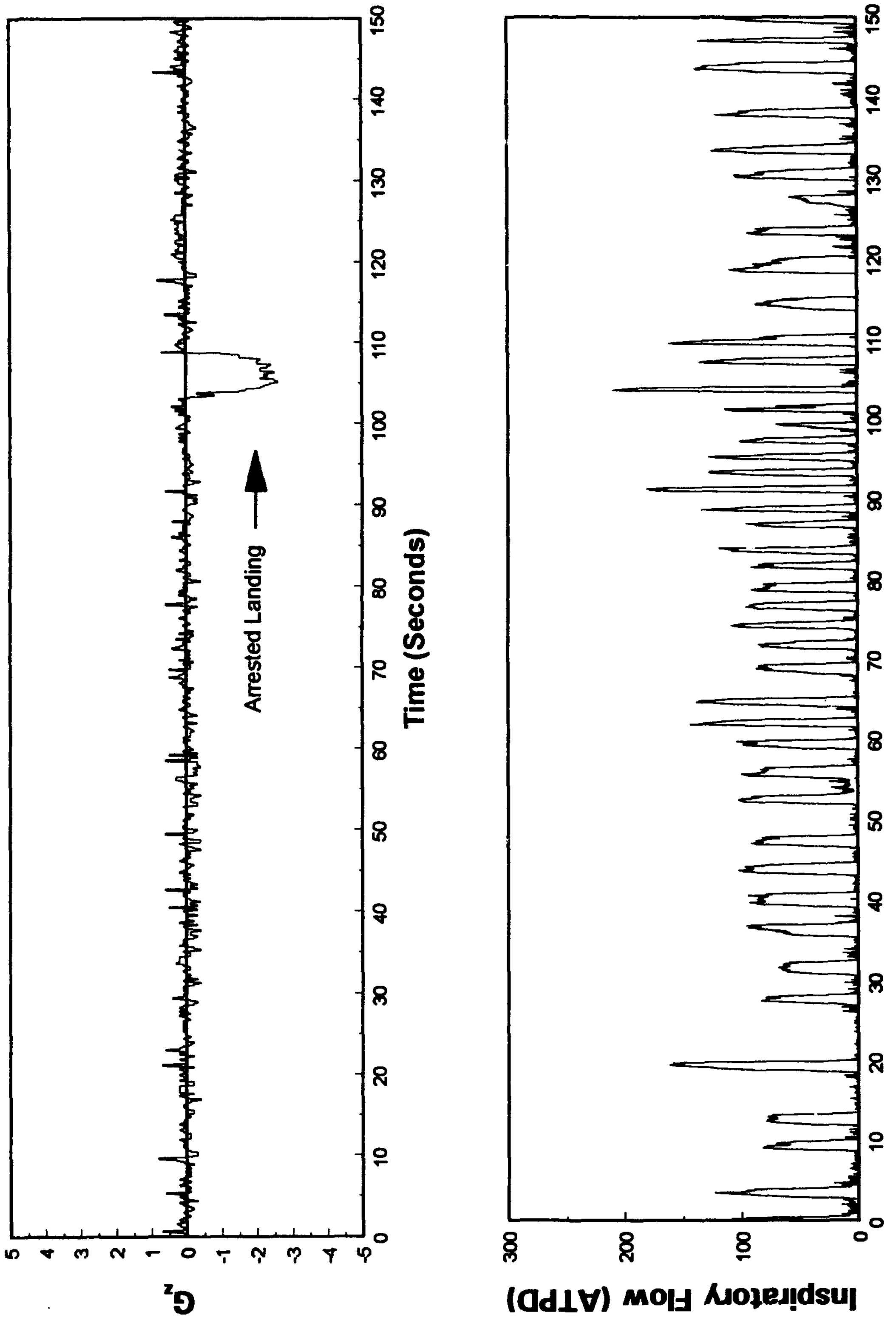

Figure 10
Typical Breathing Flow During Arrested Landing

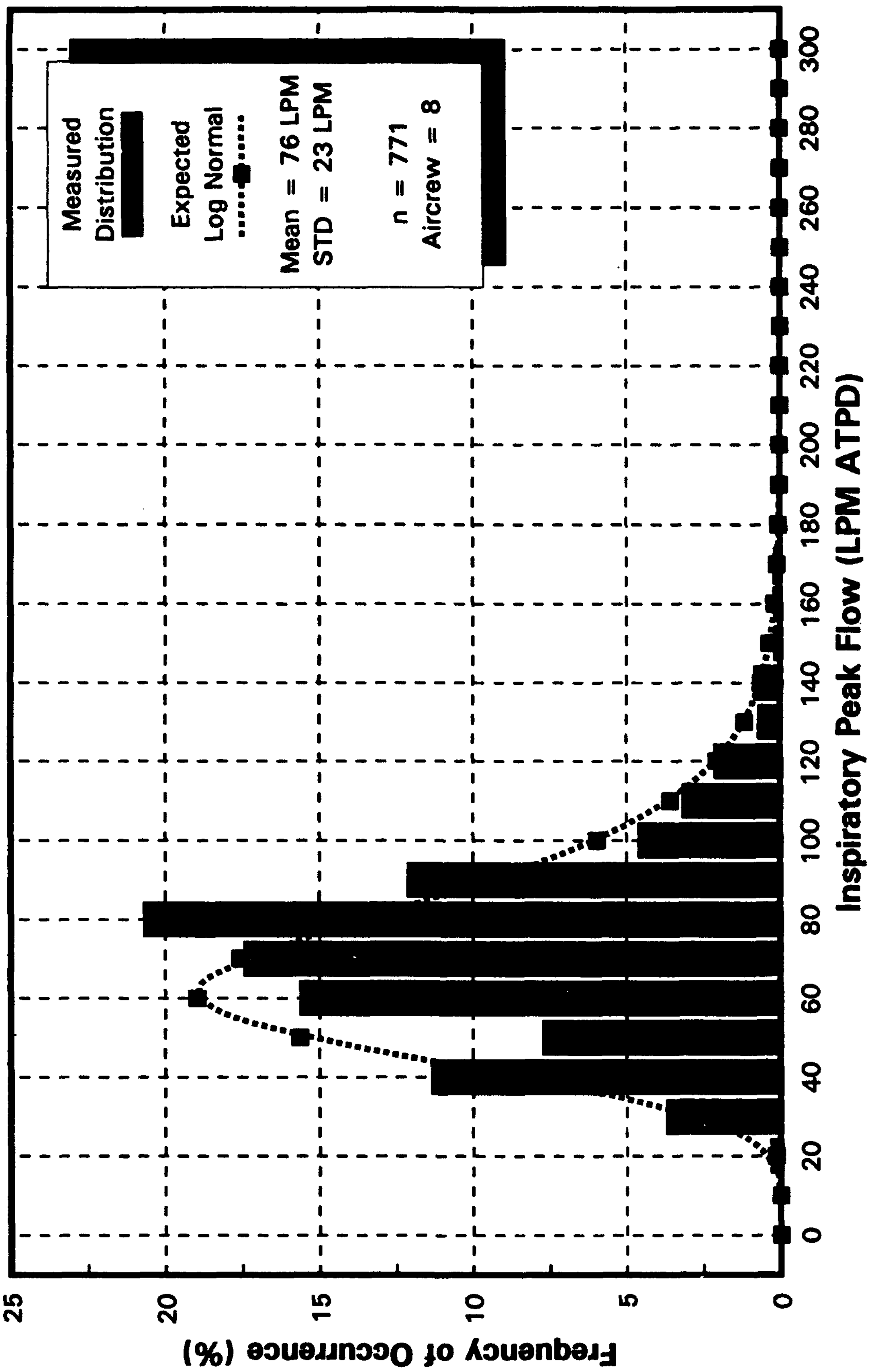

Figure 11
Peak Flow Distribution During
High-G or Aerobatic Maneuvering

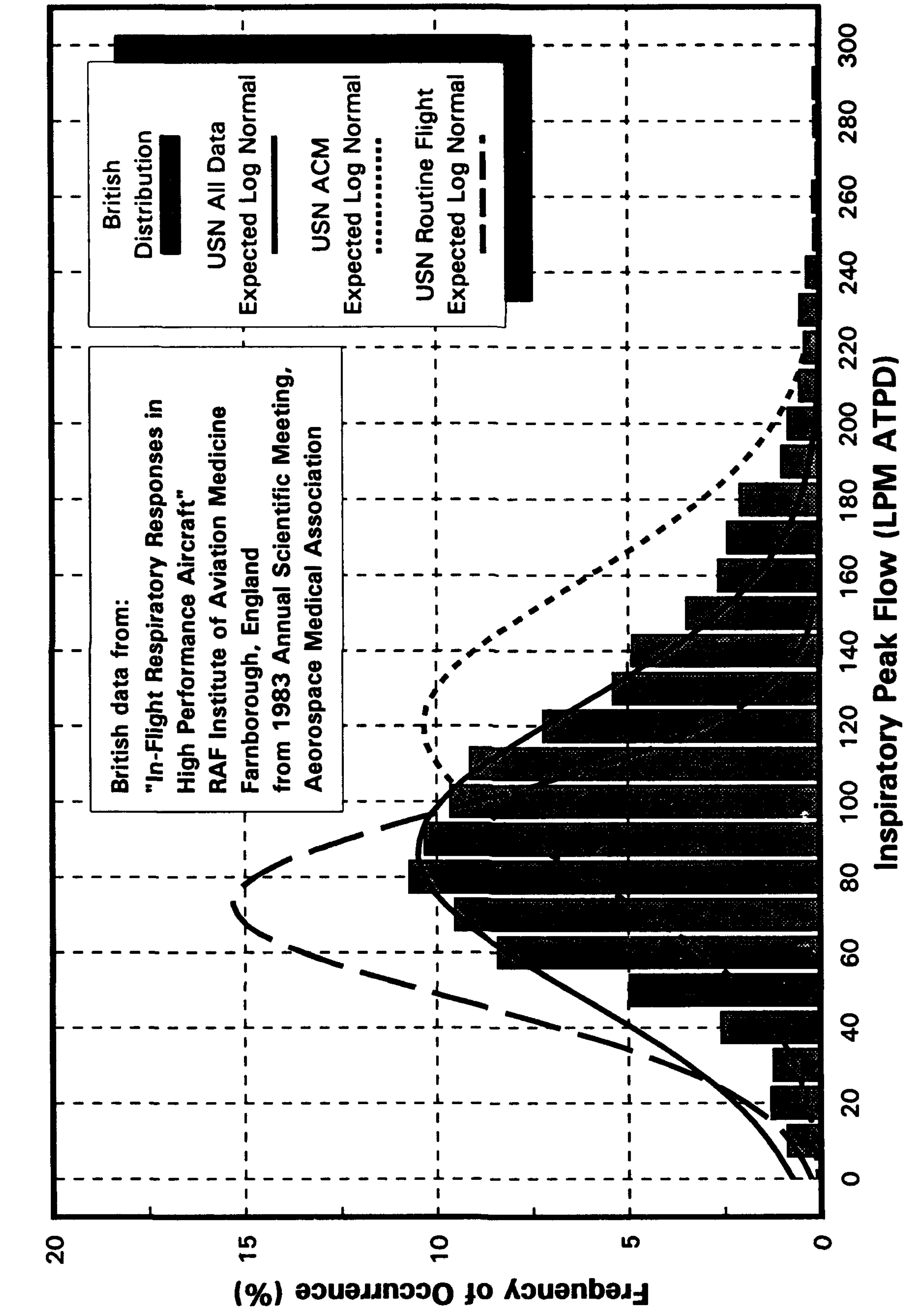

Figure 12
Peak Flow Distribution of British Data

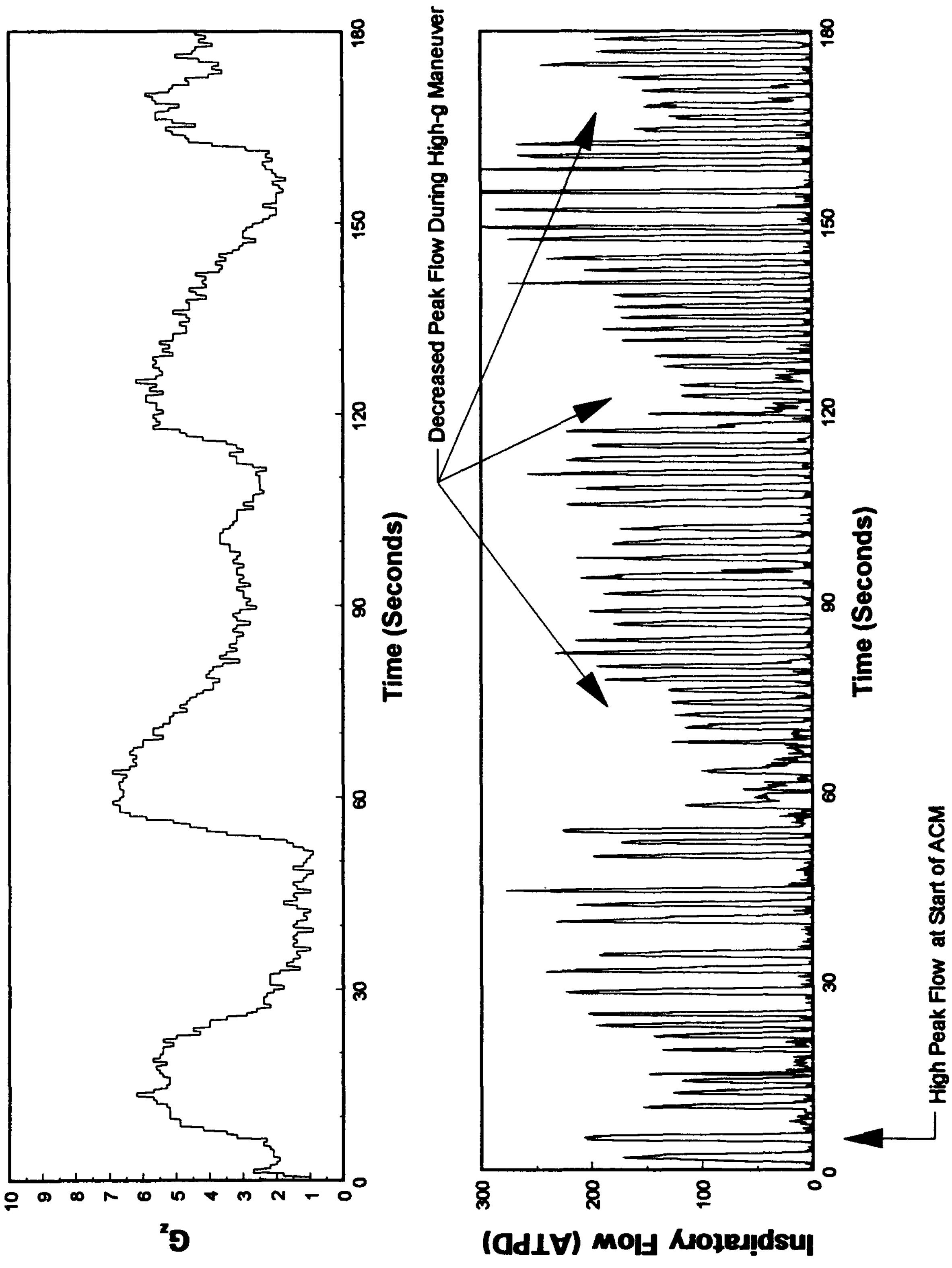

Figure 13
Breathing Flow During ACM Training

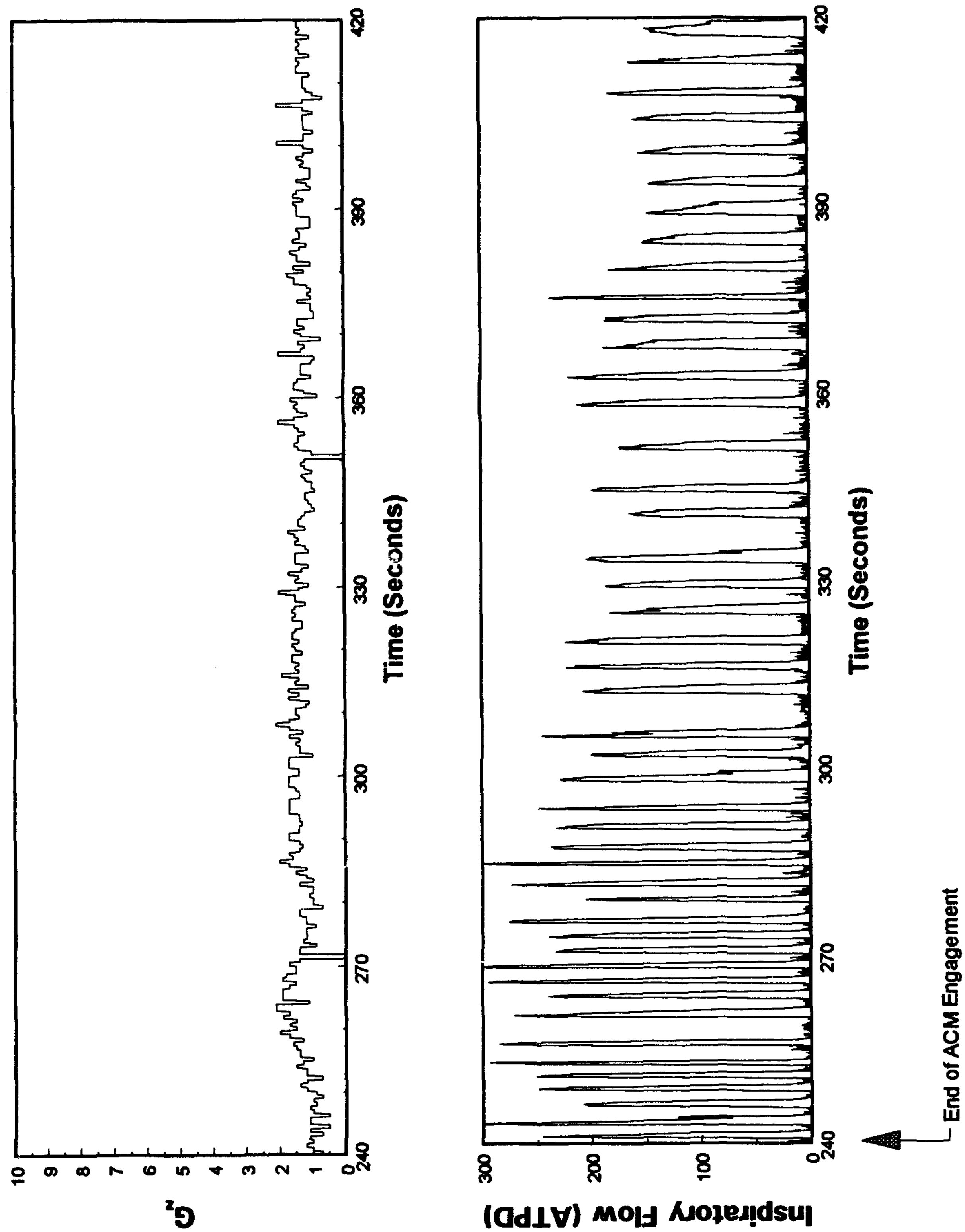

Figure 14
High Peak Flows Associated with ACM Recovery

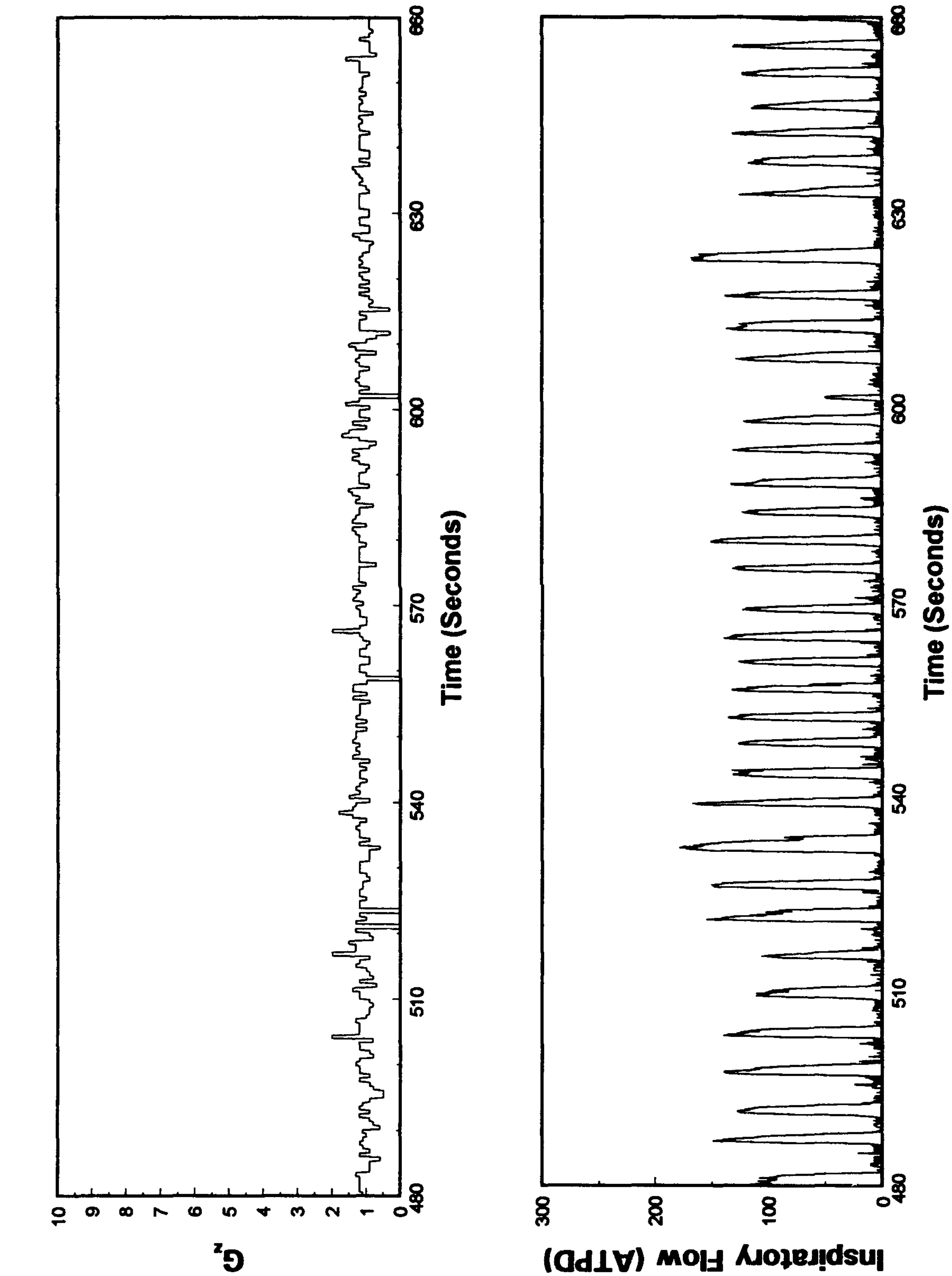

Figure 15
Normal Breathing Following ACM Recovery

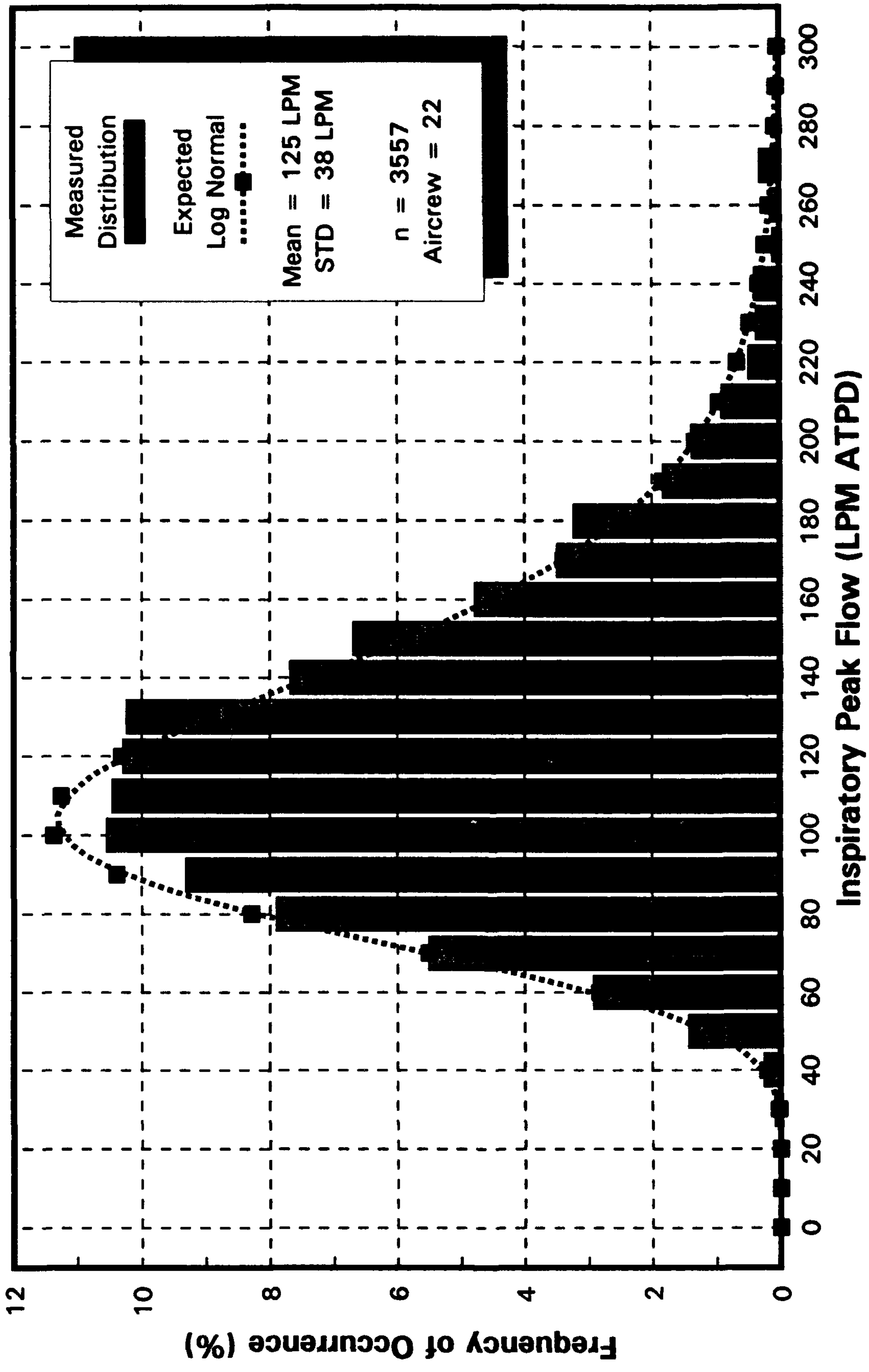

Figure 16
Peak Flow Distribution During
Aerial Combat Training

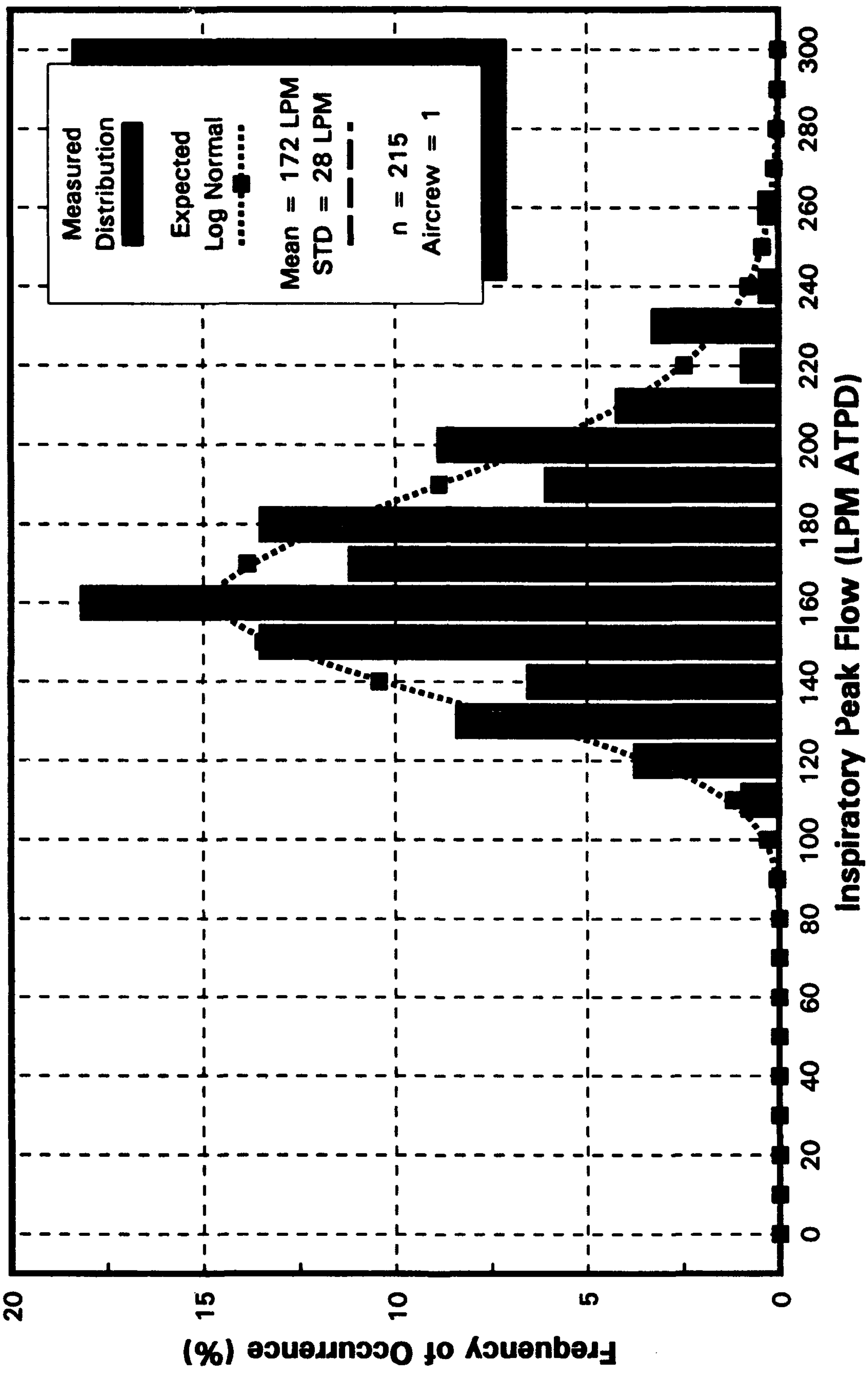

Figure 17
Peak Flow Distribution During
Aerial Combat Training for Subject #23

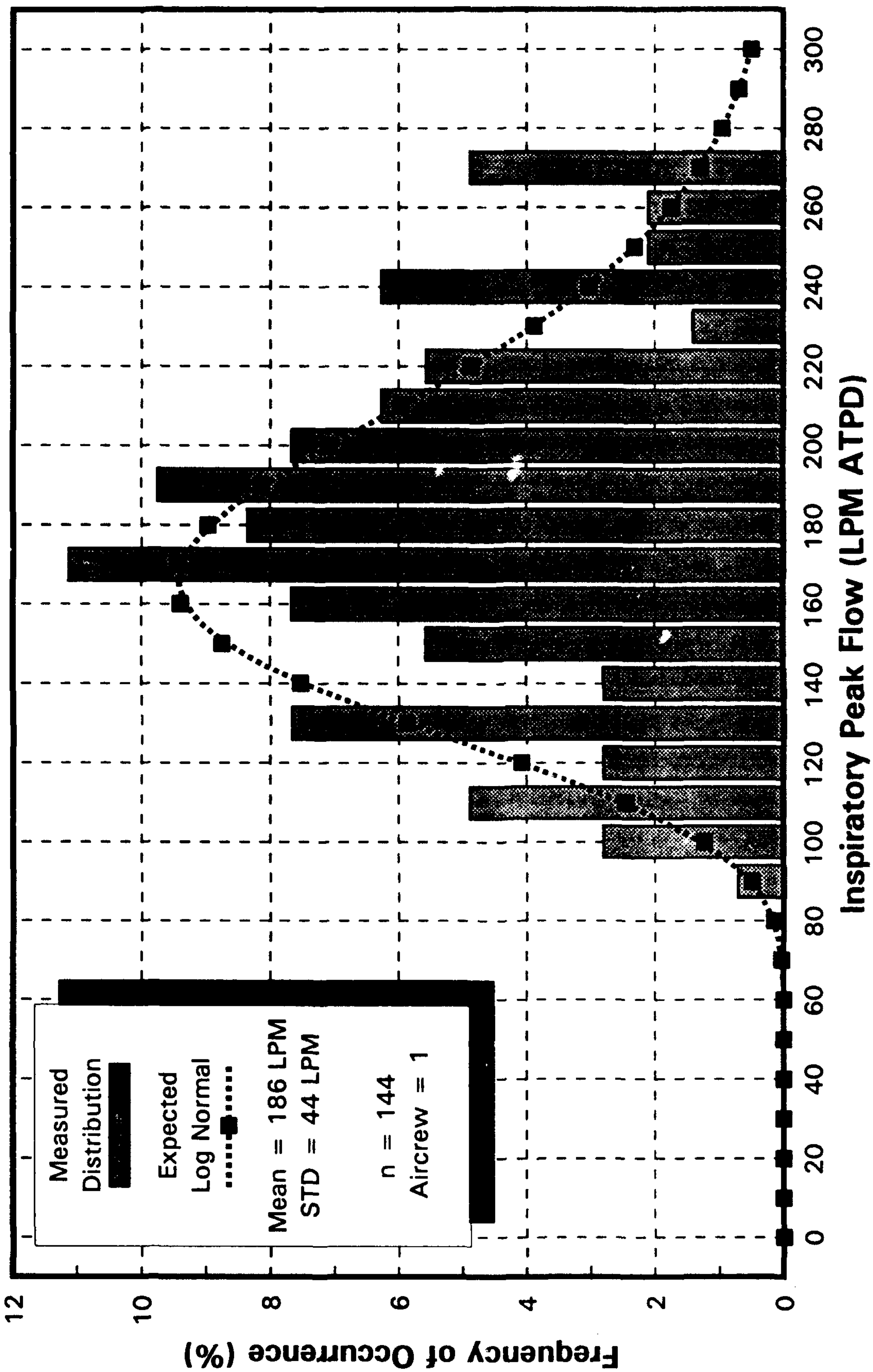

Figure 18
Peak Flow Distribution During
Aerial Combat Training for Subject #43

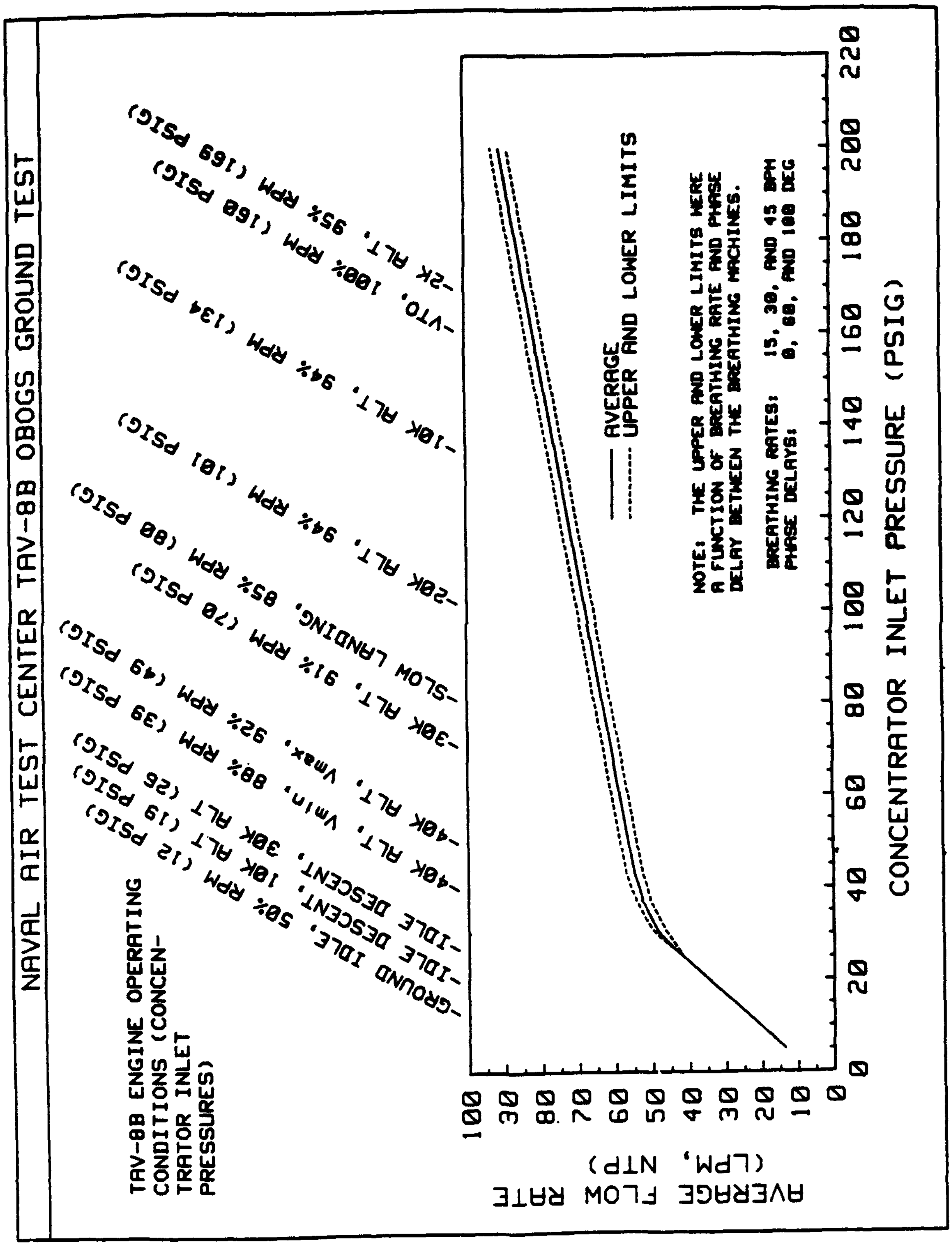

Figure 19
Breathing Performance of TAV-8B OBOGS Using Two Breathing Simulators
("Average Flow Rate" = Peak Flow / π)

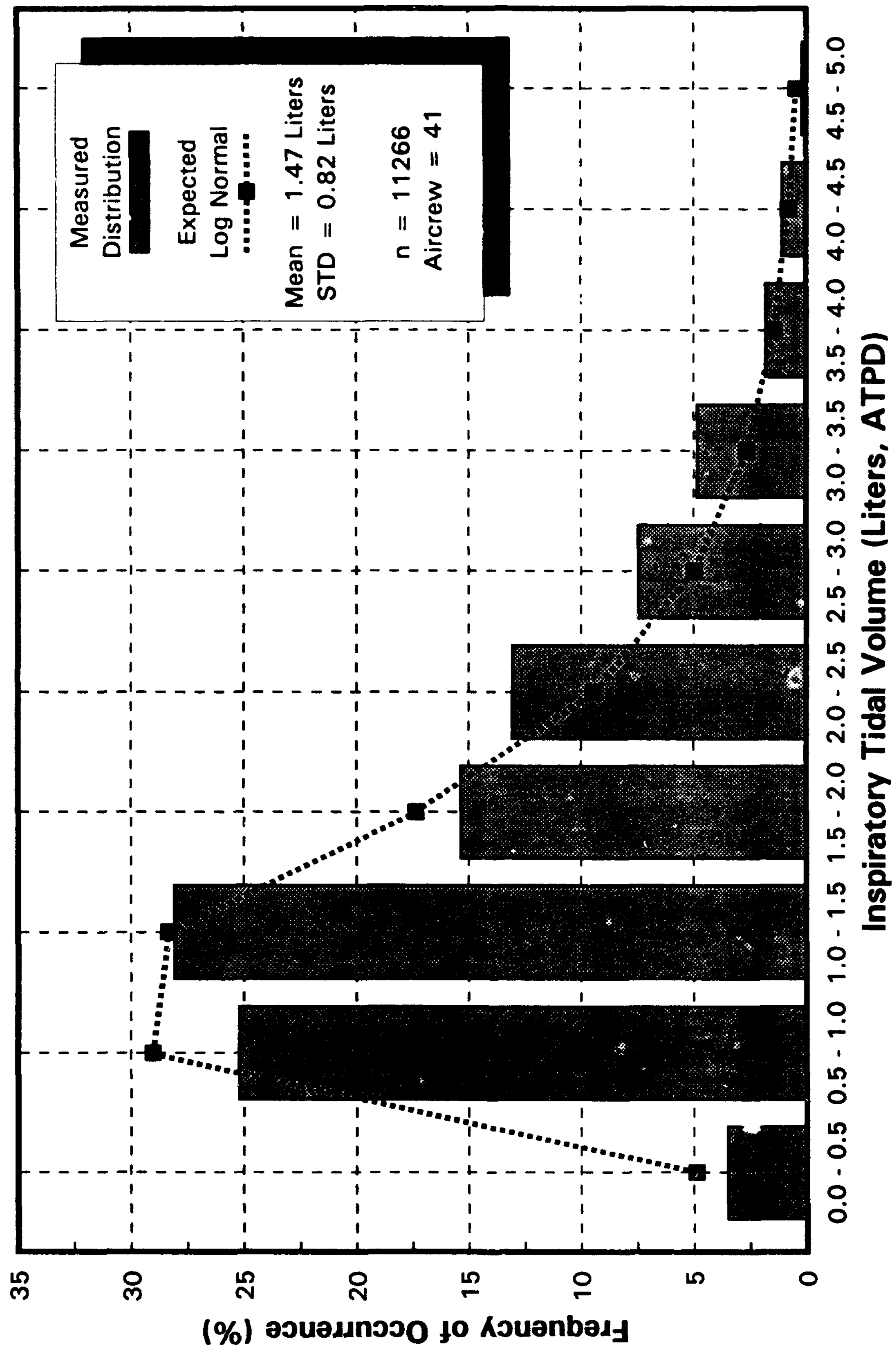

Figure 20
Tidal Volume Distribution of All Measured Data

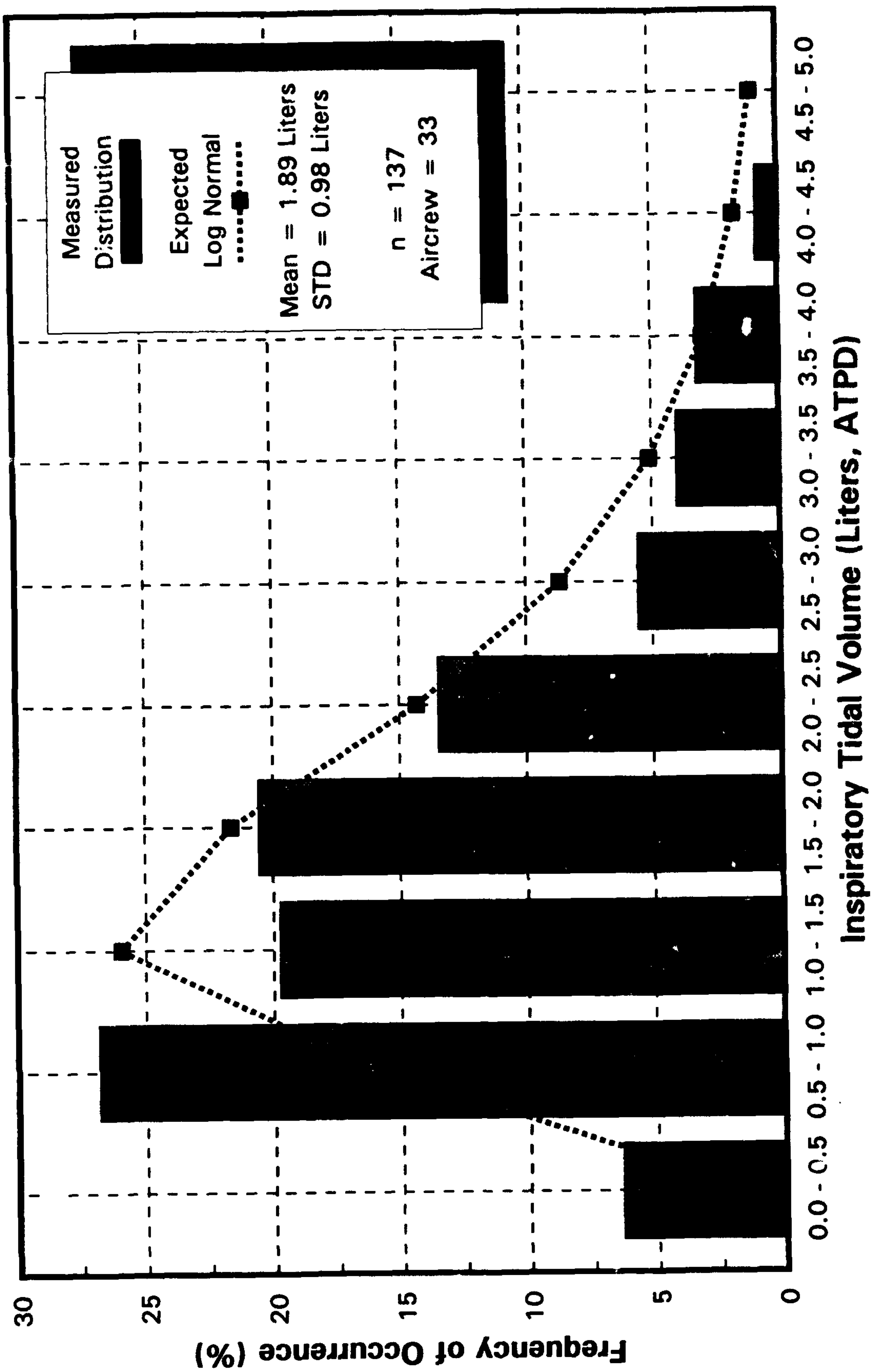

Figure 21
Tidal Volume Distribution During
System Checkout

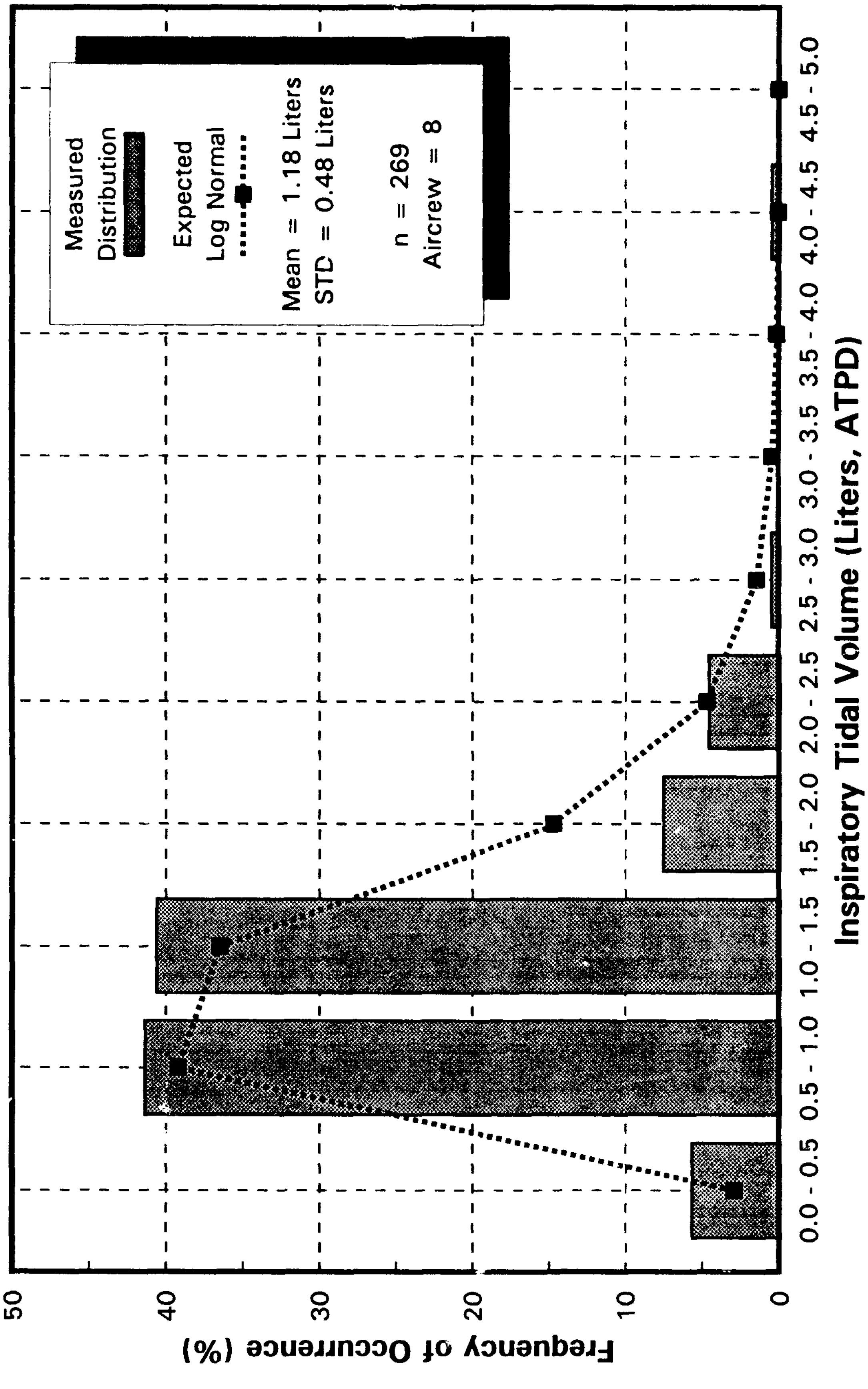

Figure 22
Tidal Volume Distribution During
Ground Operations/Taxi

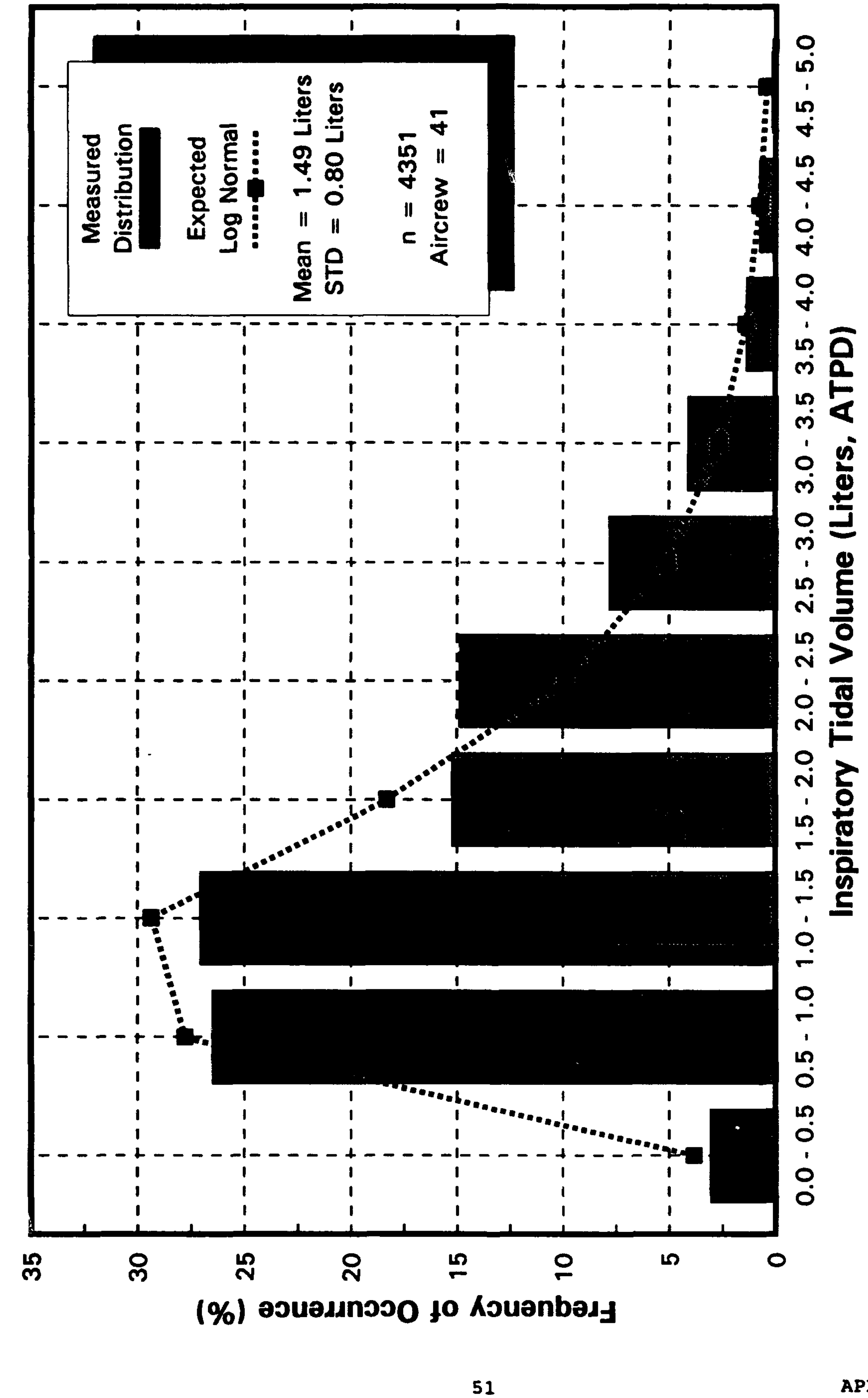

Figure 23
Tidal Volume Distribution During
Routine In-flight Operations

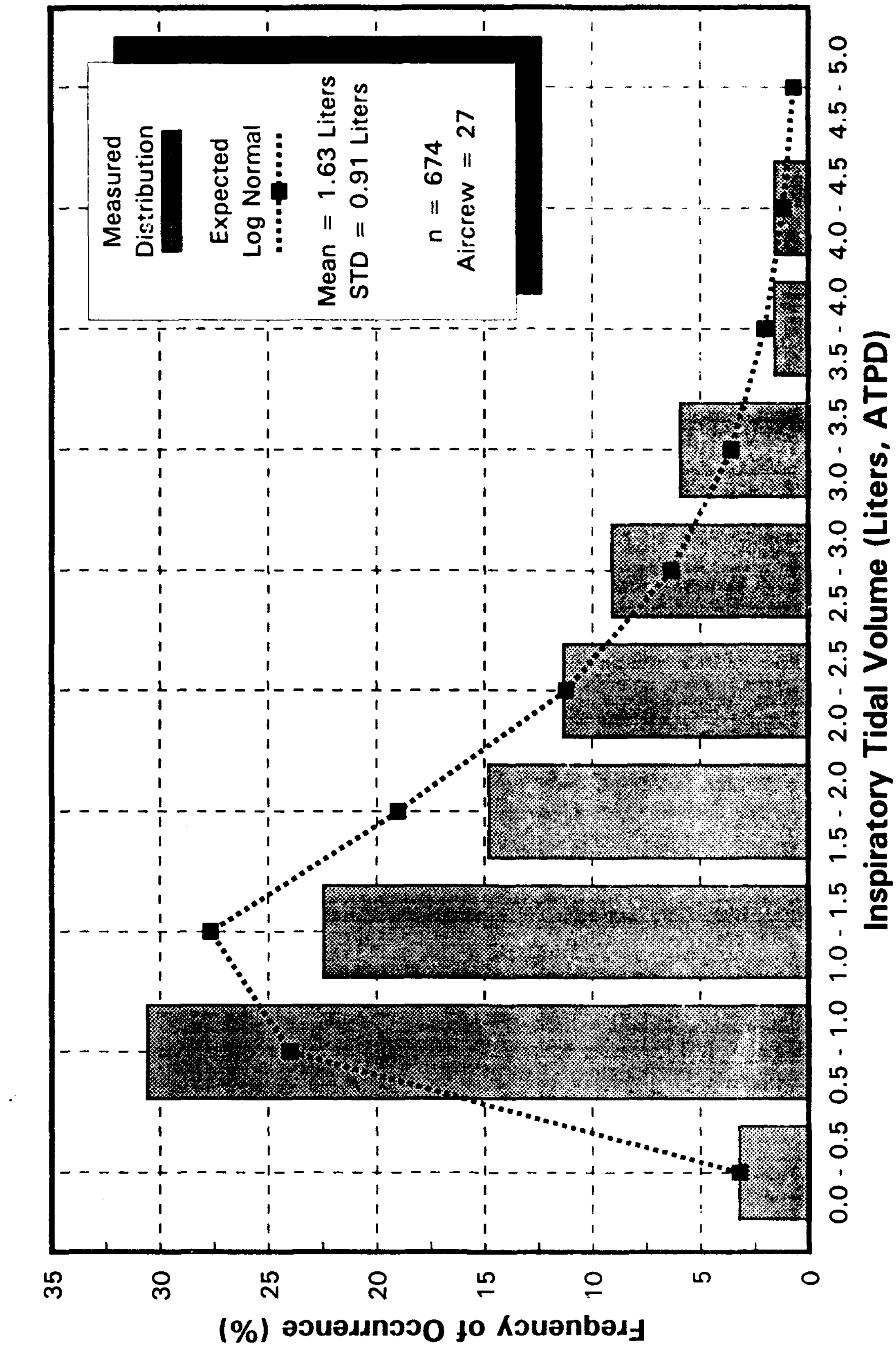

Figure 24
Tidal Volume Distribution During
Conventional (Land Based) Take Off

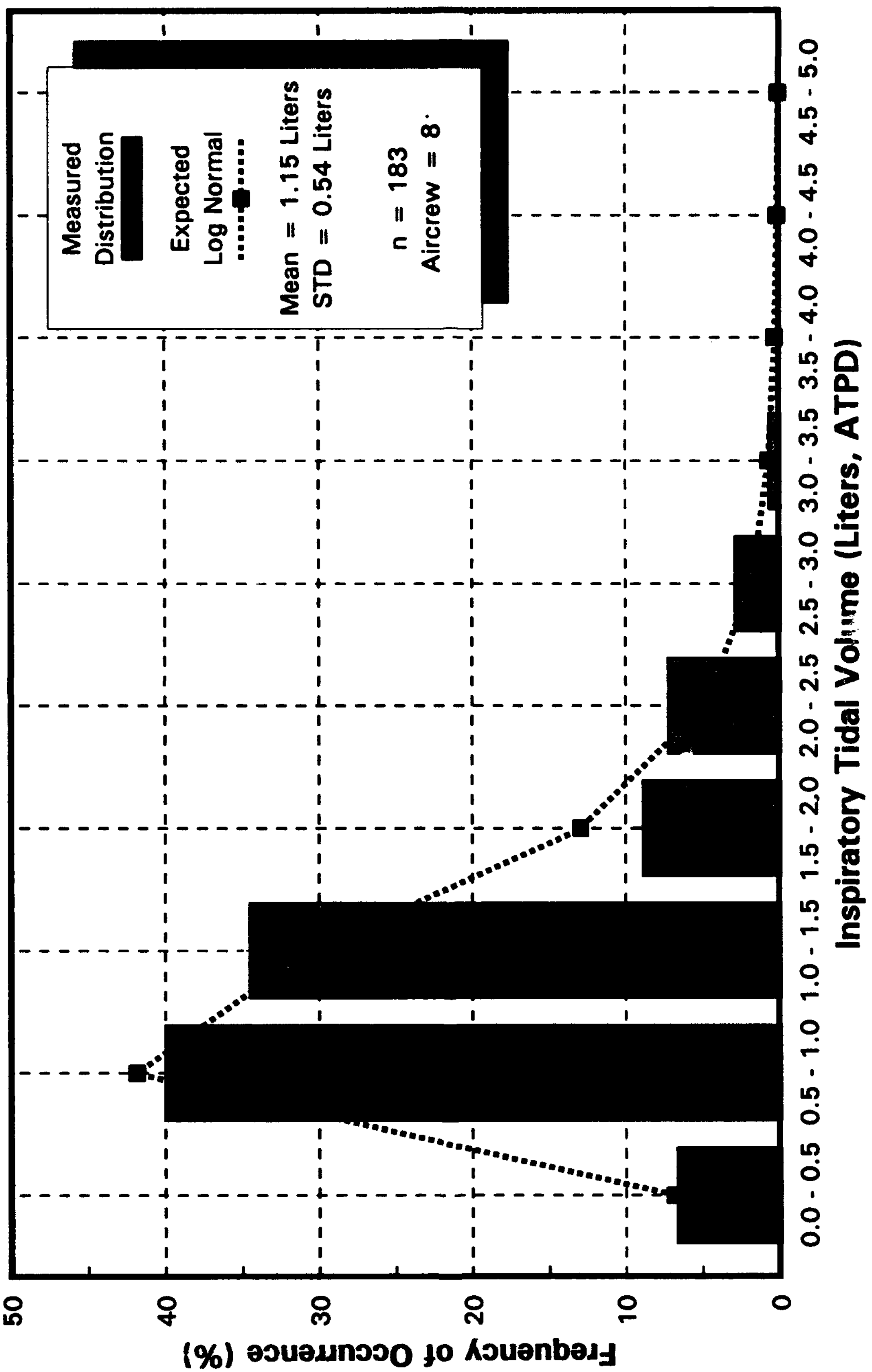

Figure 25
Tidal Volume Distribution During
Conventional (Land Based) Landing

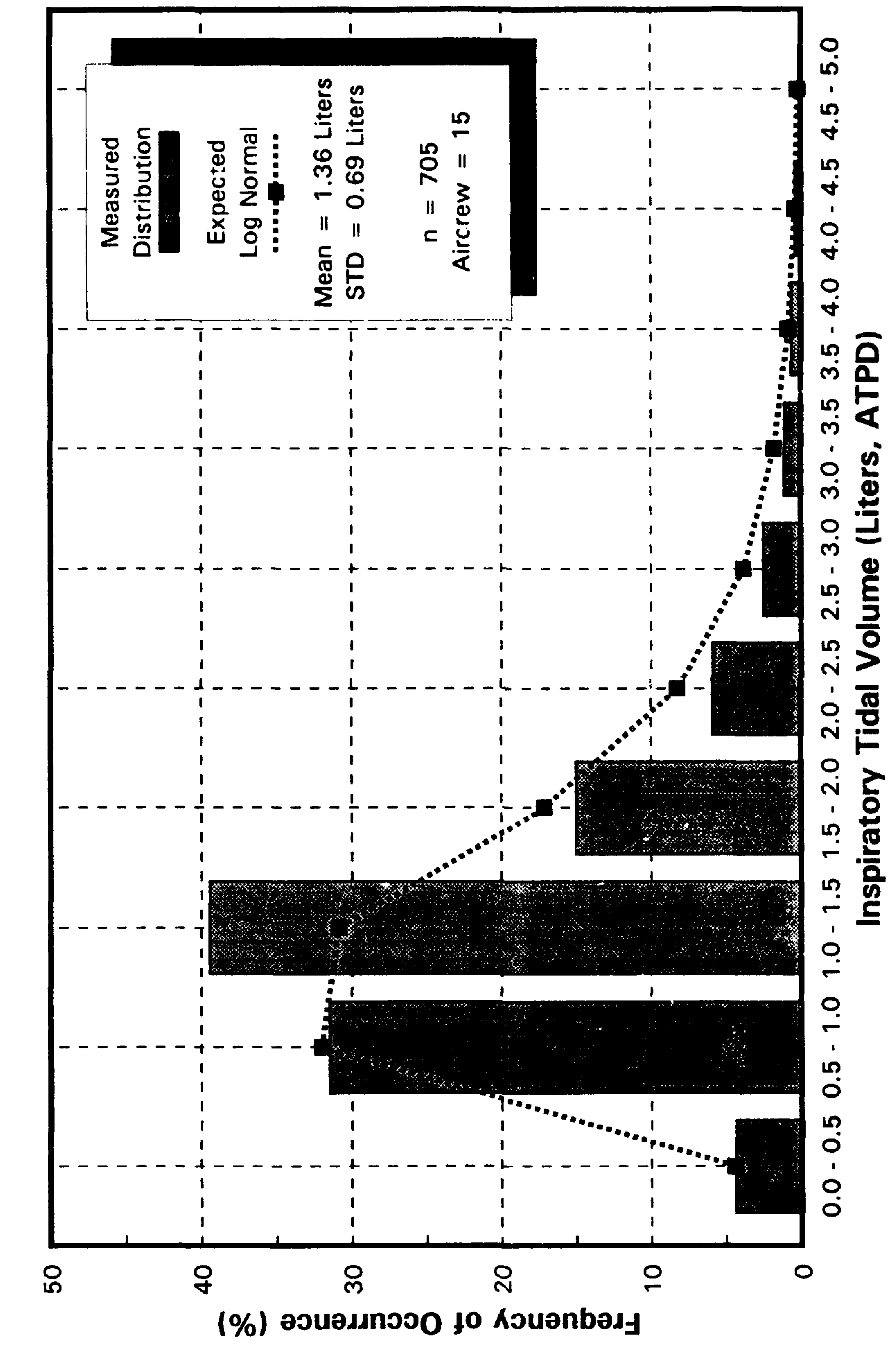

Figure 26
Tidal Volume Distribution During Catapult Launch

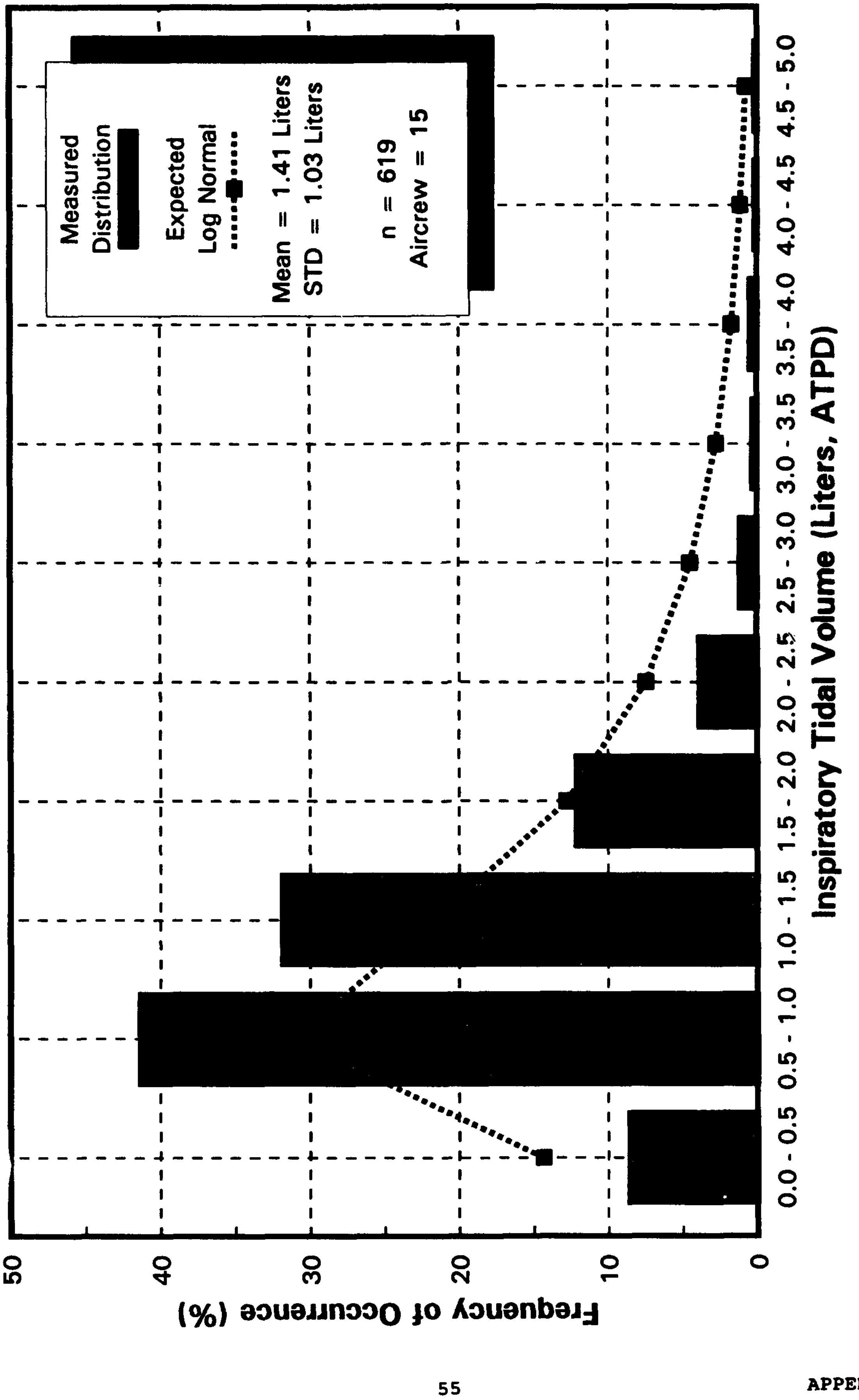

Figure 27
Tidal Volume Distribution During
Carrier Arrested Landing

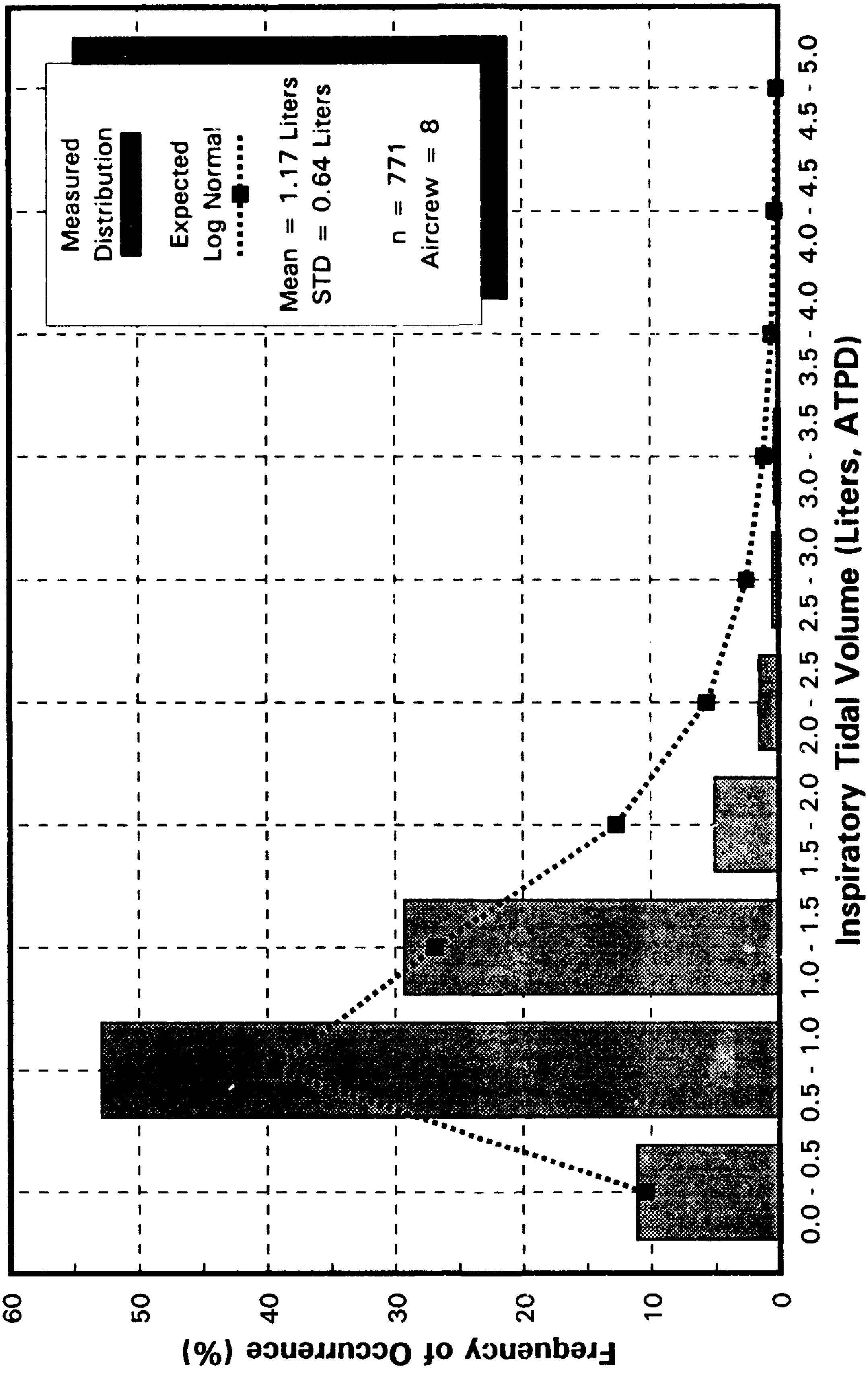

Figure 28
Tidal Volume Distribution During
High-g or Aerobatic Maneuvering

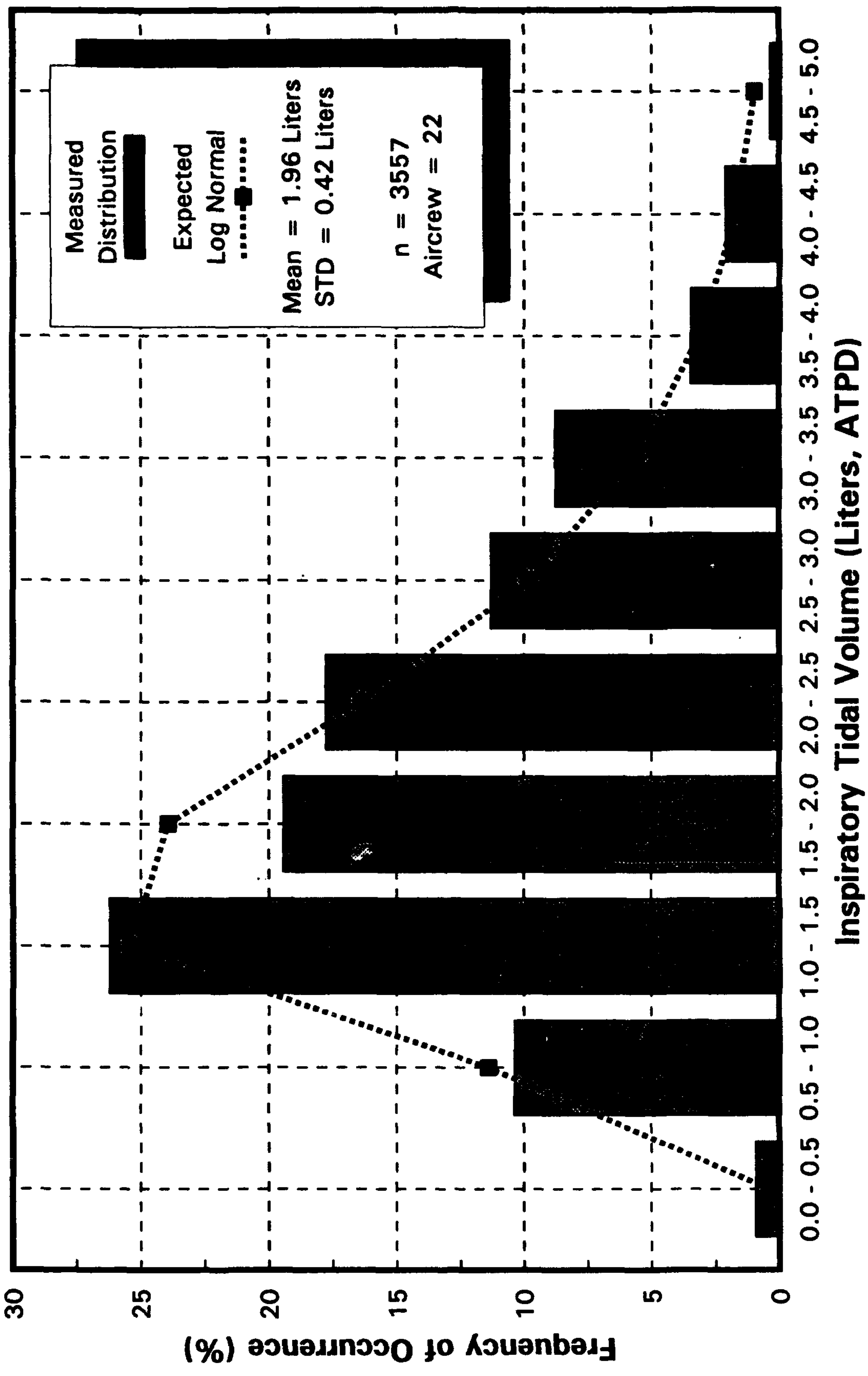

Figure 29
Tidal Volume Distribution During
Aerial Combat Training

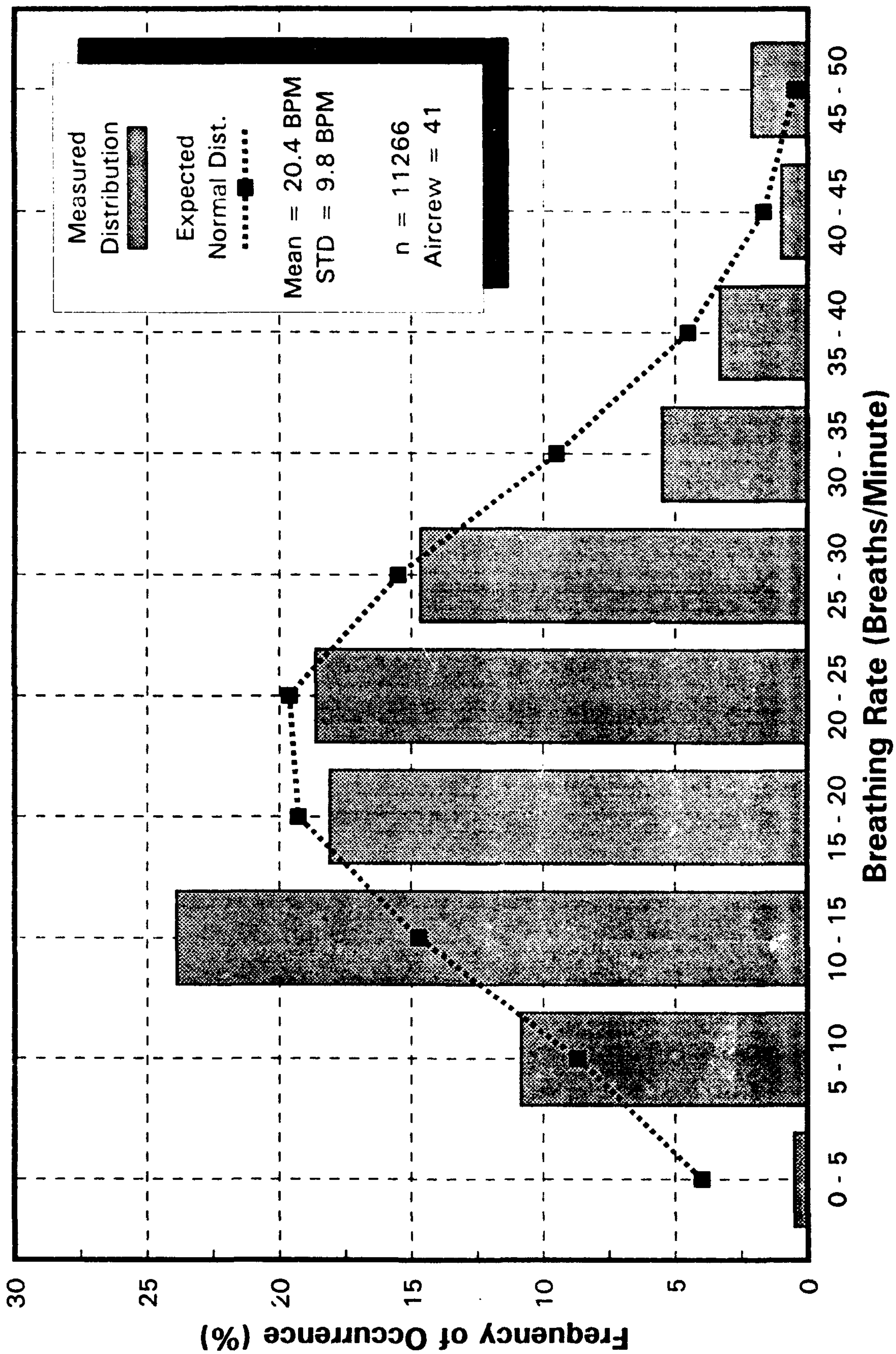

Figure 30
BPM Dist.ibution of All Measured Data

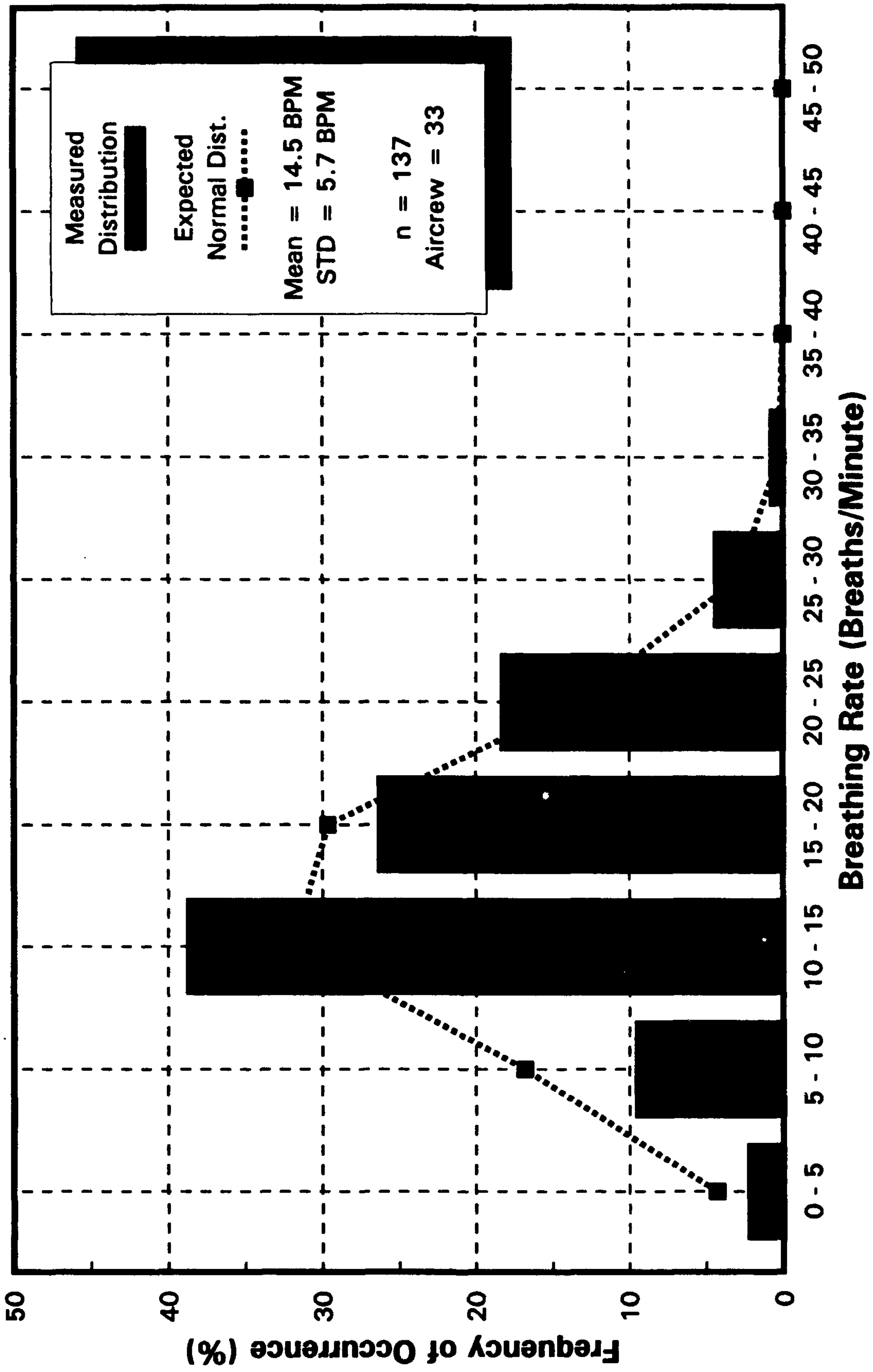

Figure 31
BPM Distribution During
System Checkout

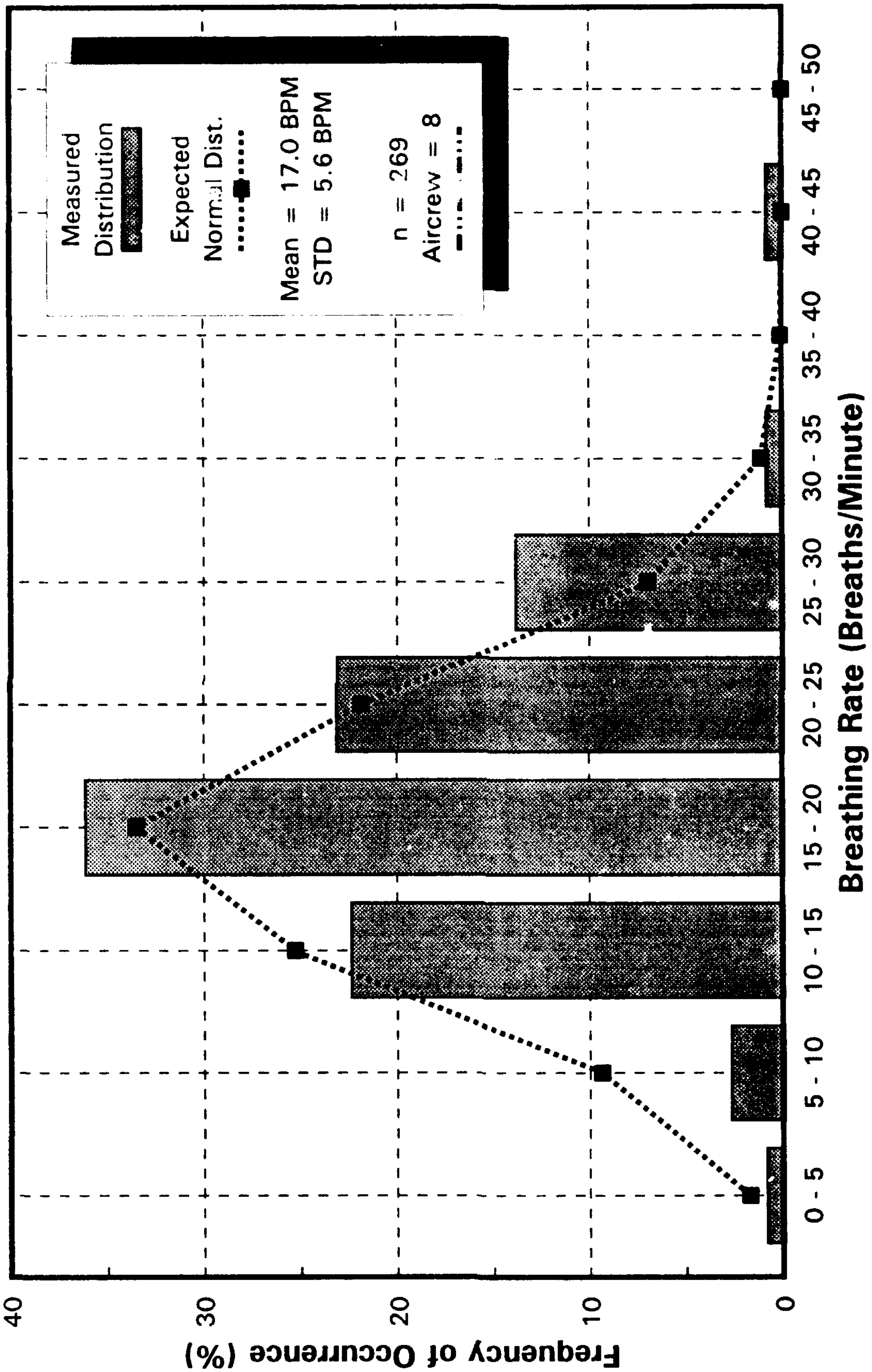

Figure 32
BPM Distribution During
Ground Operations/Taxi

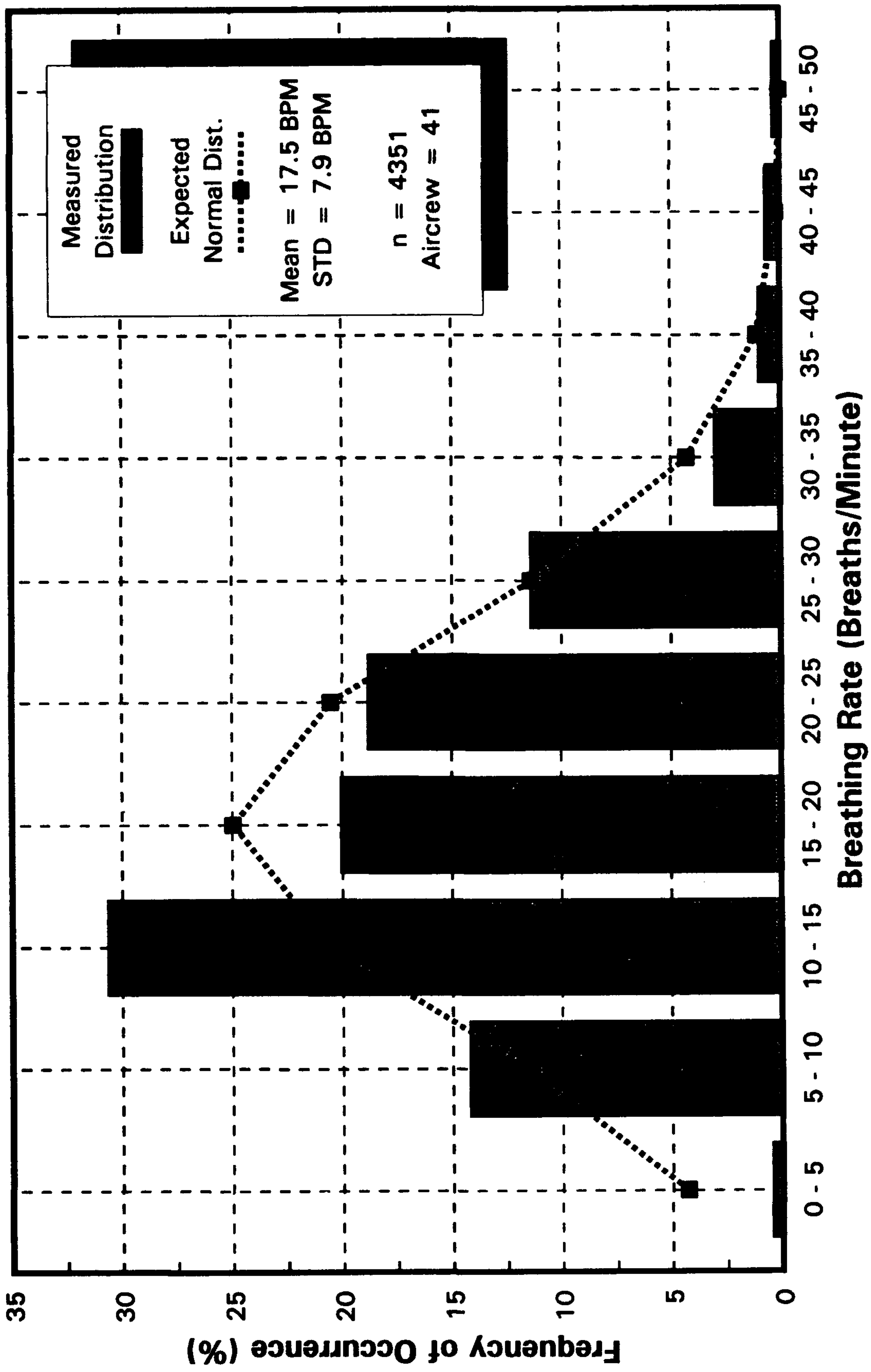

Figure 33
BPM Distribution During
Routine In-flight Operations

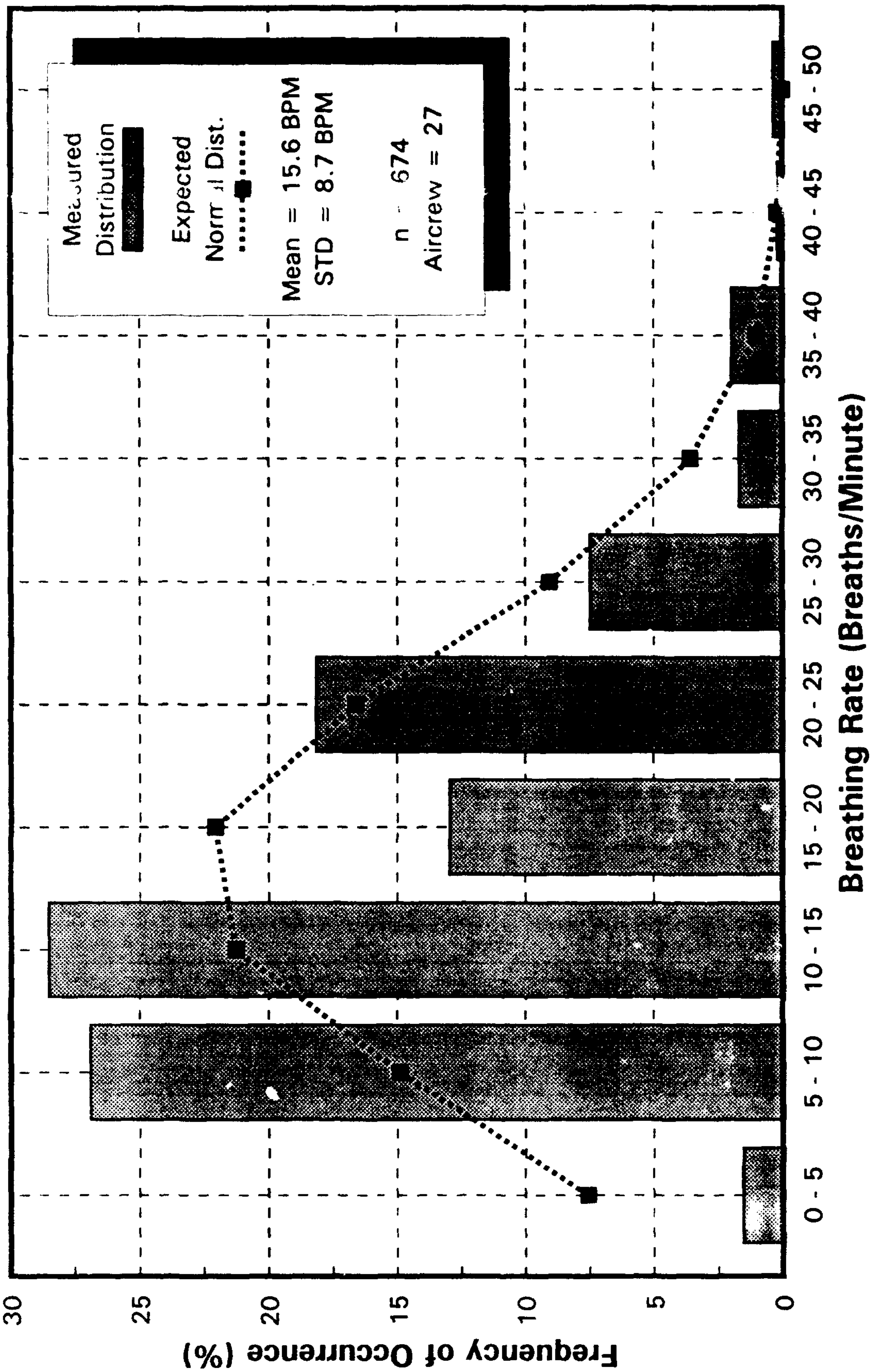

Figure 34
BPM Distribution During
Conventional (Land Based) Take Off

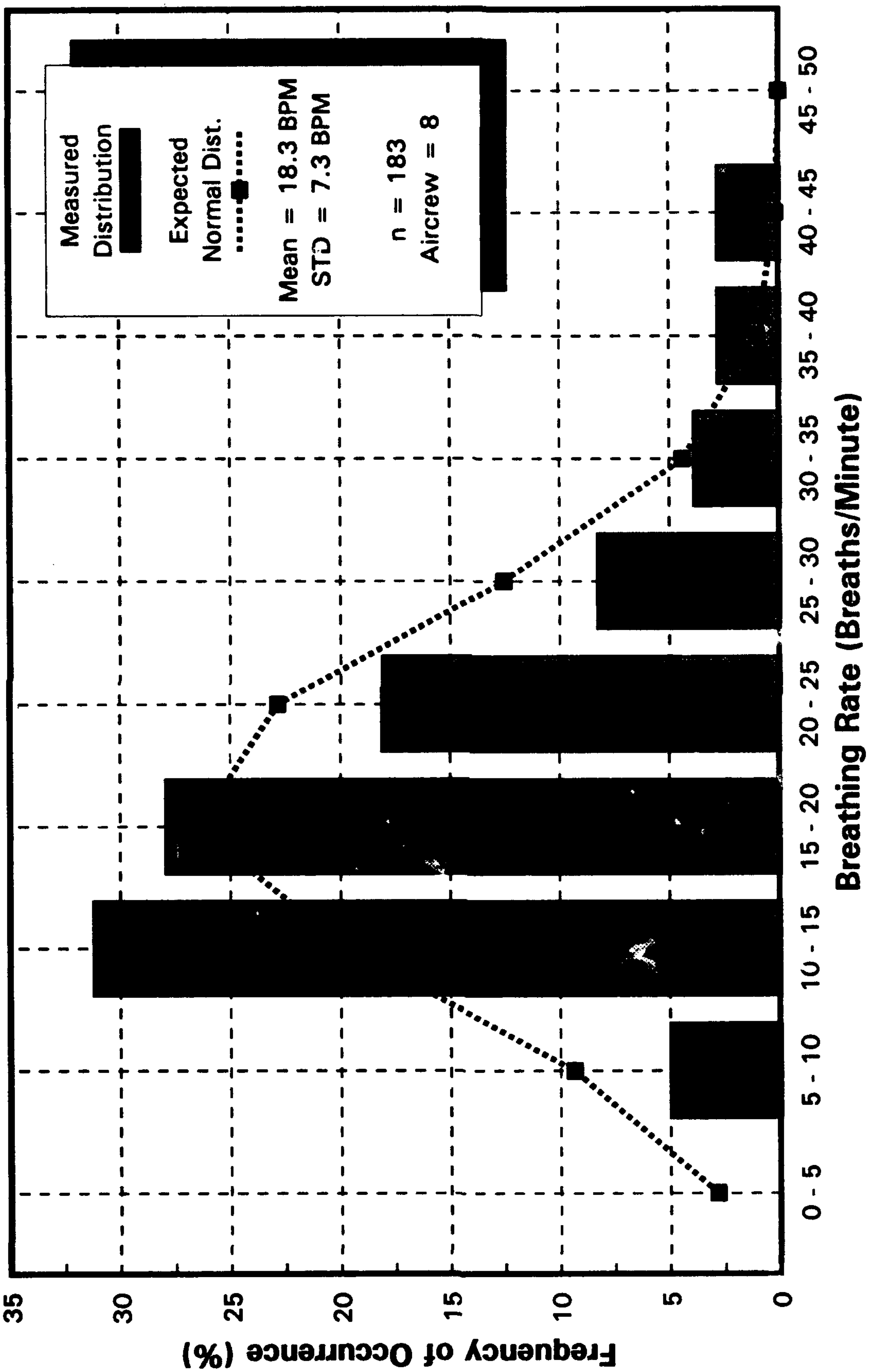

Figure 35
BPM Distribution During
Conventional (Land Based) Landing

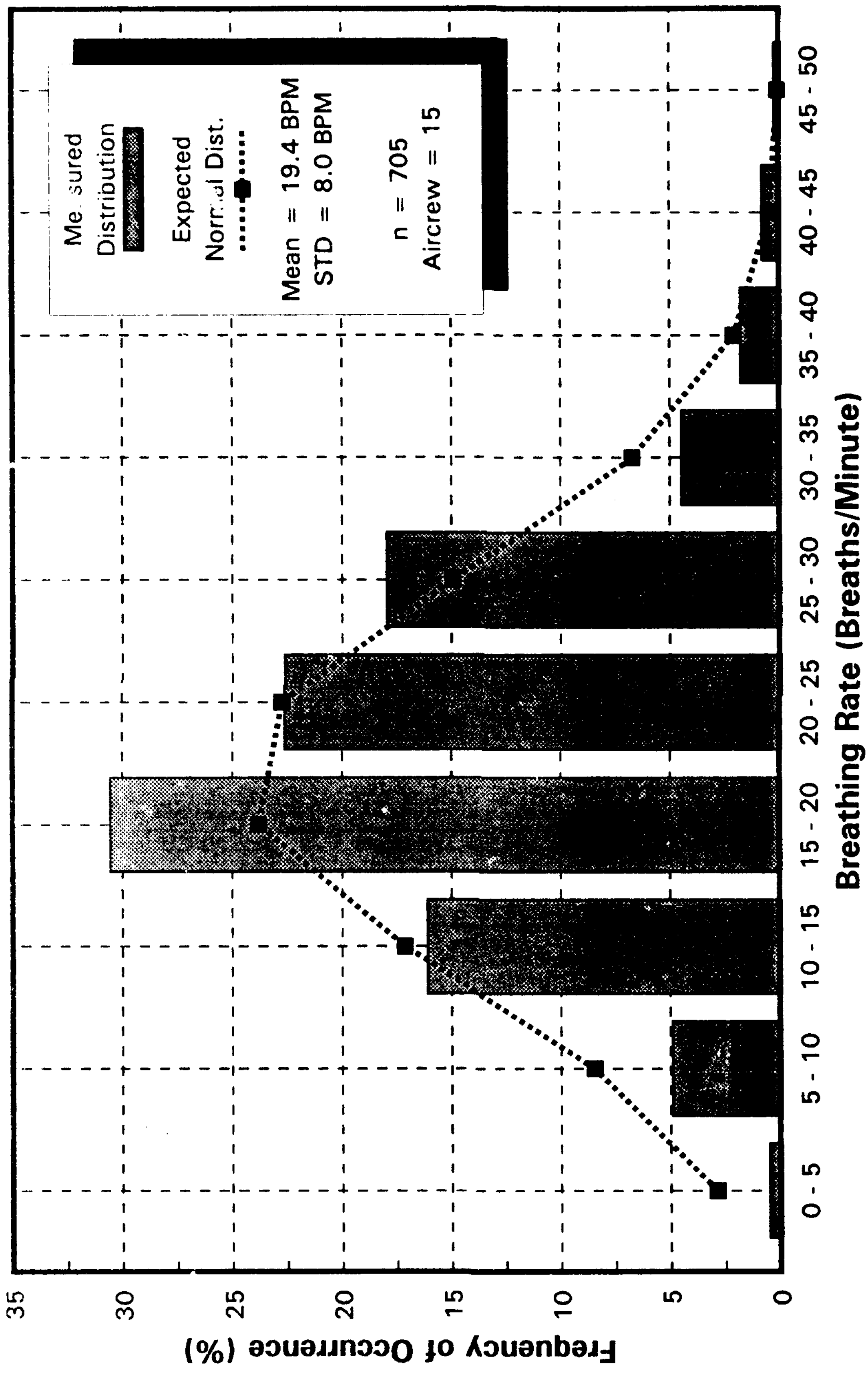

Figure 36
BPM Distribution During Catapult Launch

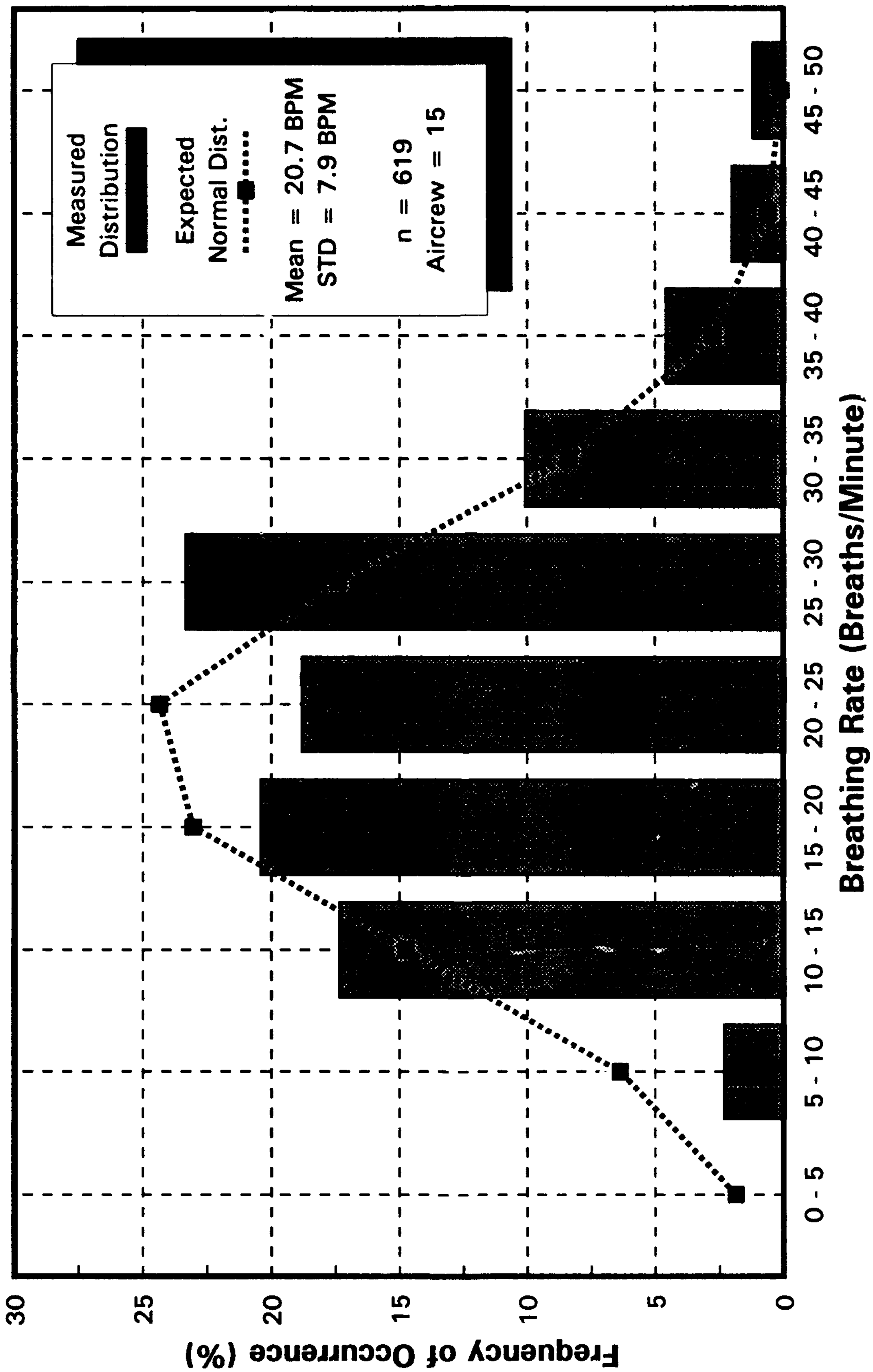

Figure 37
BPM Distribution During
Carrier Arrested Landing

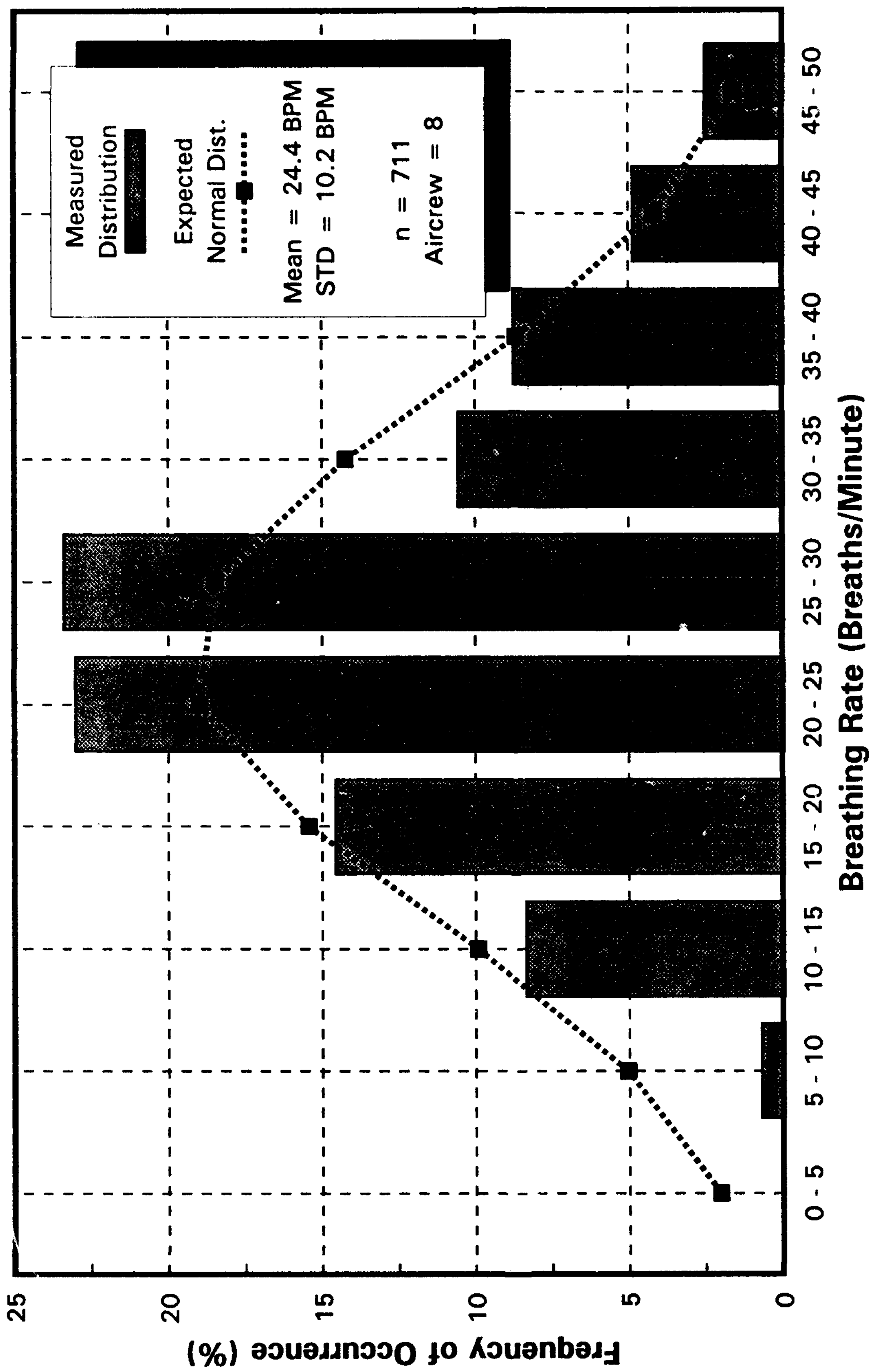

Figure 38
BPM Distribution During
High-g or Aerobatic Maneuvering

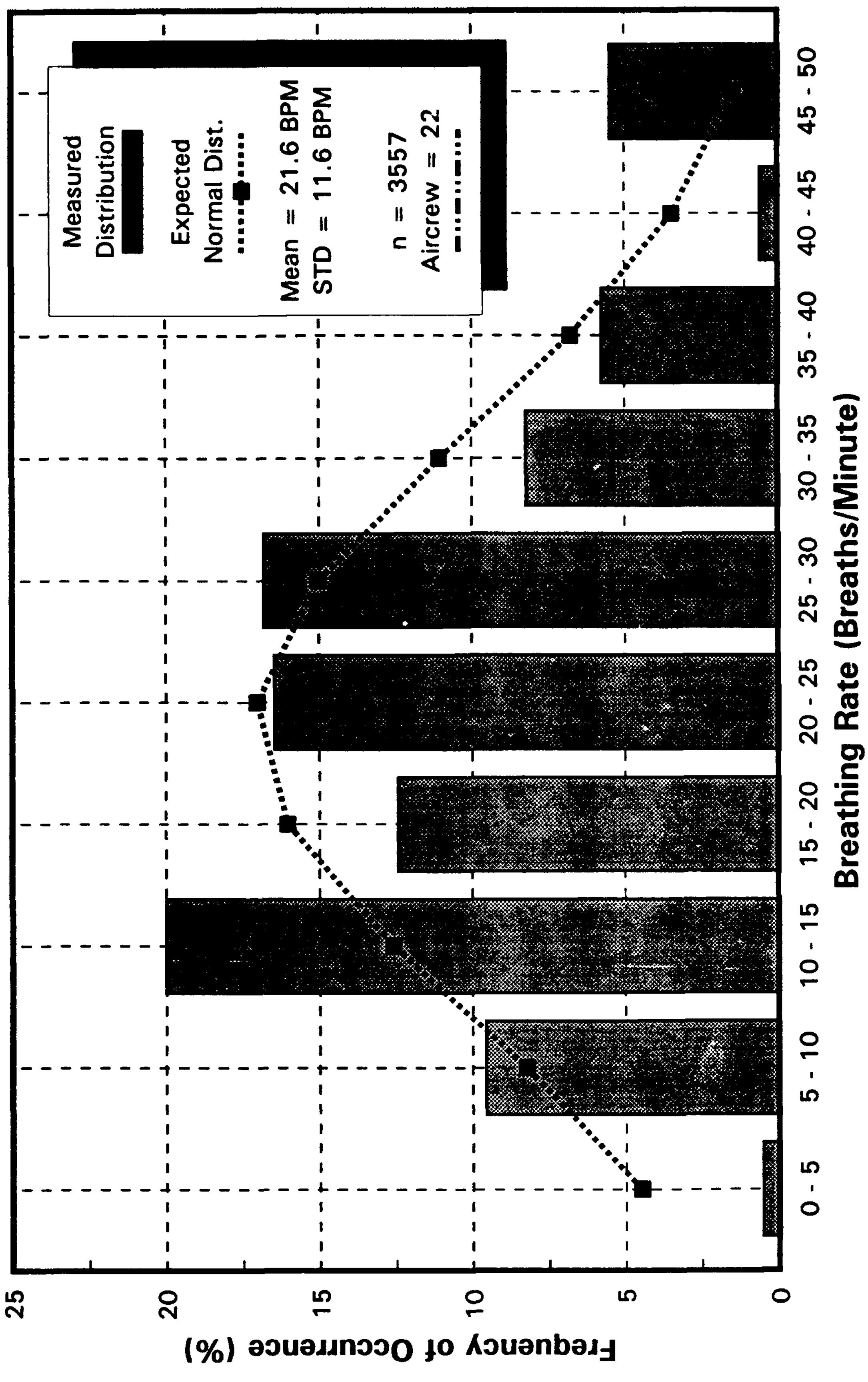

Figure 39
BPM Distribution During
Aerial Combat Training

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTION:

NAVAIRSYSCOM (AIR-531)	(3)
NAVAIRSYSCOM (AIR-531B)	(1)
NAVAIRSYSCOM (AIR-5116F)	(1)
NAVAIRSYSCOM (AIR-5116B)	(1)
NAVAIRSYSCOM (AIR-5114A)	(1)
NAVAIRSYSCOM (AIR-5114D)	(1)
NAVAIRSYSCOM (AIR-5116E)	(1)
NAVAIRSYSCOM (AIR-5114F)	(1)
NAVAIRSYSCOM (AIR-531TA)	(1)
NAVAIRSYSCOM (PMA202)	(1)
NAVAIRSYSCOM (PMA205)	(1)
NAVAIRWARCENACDIV Warminster, PA (Code 60B1)	(3)
NAVAIRWARCENACDIV Warminster, PA (Code 602)	(3)
NAVAIRWARCENACDIV Warminster, PA (Code 603)	(3)
BUMED, Washington, D.C. (Code 231)	(1)
NAOMI, Pensacola, FL (Code 00MM)	(1)
USAF ASC/ENSC Wright-Patterson AFB, OH	(2)
USAF ASC/YFFC Wright-Patterson AFB, OH	(1)
USAF ASC/SDE Wright-Patterson AFB, OH	(1)
USAF AL/CFT Brooks AFB, TX	(1)
USAF AL/CFTS Brooks AFB, TX	(1)
NAVAIRWARCENACDIV Patuxent River, MD (CT53)	(3)
NAVAIRWARCENACDIV Patuxent River, MD (SY73)	(25)
NAVAIRWARCENACDIV Patuxent River, MD (RW)	(1)
NAVAIRWARCENACDIV Patuxent River, MD (FW)	(1)
NAVAIRWARCENACDIV Patuxent River, MD (SA)	(1)
NAVAIRWARCENACDIV Patuxent River, MD (TPS)	(1)
DTIC	(2)